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AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

A report of work done by scientists of 5 campuses of the University of California (Davis, Berkeley, Santa Barbara, Los Angeles and Riverside) under NASA Grant NGL 05-003-404

Annual Progress Report

1 May 1973

UNIVERSITY OF CALIFORNIA, BERKELEY

PREFACE

Since May, 1970 personnel on several compuses of the University of California have been conducting a NASA-funded investigation which seeks to determine the usefulness of modern remote sensing techniques for studying various components of California's earth resources complex. From the outset most of this work has concentrated on California's water resources, but with some attention being given to other earth resources as well and to the interplay between them and California's water resources.

In its broadest sense, the term "earth resources" pertains to all matter that is present at or near the surface of the earth, be it mineral, vegetable or animal. Thus it includes not only relatively inert components as rocks, soil, water and air; it also includes such dynamic components as timber, forage and agricultural crops, as well as livestock, fish and wildlife.

The fact that these resources must be managed as wisely as possible has come to our attention with increasing forcefulness in recent years. A genuine sense of urgency, in fact, has resulted from our realization that the demand for these resources, whether on a local, regional or global basis, is rapidly increasing at the very time when the supply of many of them is rapidly diminishing or their quality is rapidly deteriorating.

The rationale by which remote sensing of the earth's surface can lead to wise management of the earth's resources is not a complex one. In fact it can be expressed in a simple two-part statement, as follows:

1. Wise management of these resources is greatly facilitated if timely, accurate inventories of them are periodically made available to the resource manager so that he will know at all times "how much" of "what" he has "where".

2. Almost invariably the making of such inventories can be greatly facilitated through the use of modern remote sensing techniques by means of which photographs and related records about these resources are obtained periodically from aircraft and spacecraft. The favorable vantage point offered by these two kinds of vehicles is of great importance. Since the face of the land looks to the sky, it often is the view of the earth's surface as obtained from an aircraft or spacecraft which can best provide the resource manager with the information that he needs.

The study dealt with in this Progress Report seeks to apply the foregoing concepts in the making of an integrated study of earth resources in the state of California using remote sensing techniques. Many of the earth resource components in California, as in most other parts of the world, are dynamic rather than static. Therefore, it is necessary for these resources to be inventoried frequently and rapidly -- frequently so that resource trends can be followed -- rapidly so that resource management decisions can be made and implemented while the inventory data are still current. Our present studies, based largely on NASA-flown photography, are giving major emphasis to such considerations. These studies give particular consideration to the opportunities that currently are being afforded for satisfying these requirements through the use of data being acquired by the first Earth

Resources Technology Satellite (ERTS-1).

The wise management of earth resources in an area such as the state of California depends, however, on far more than the mere acquiring of timely, accurate resource inventories. Even when given such information, the resource manager could easily make wrong decisions if he were to ignore certain important socio-economic factors. Alternately stated, human needs and emotions cannot be overlooked (particularly in these days of the environment "crusaders") as we seek better to manipulate earth resources, whether on a local, regional, national or global basis.

As will be indicated in the present progress report, due consideration is being given to each of the foregoing factors in this "integrated" study.

Robert N. Colwell
Principal Investigator
June 30, 1973

TABLE OF CONTENTS

Chapter 1

INTRODUCTION

From the outset those of us who have been participating in this project have recognized that little would be accomplished if we attempted to investigate, at the outset, all components of California's entire earth resources complex statewide. Ideally we would begin our study by investigating some discrete phase of this complex which, although of limited scope, would require a consideration of both the resource interrelationships and the attitudes of the people in a very sizeable part of the state. Given these ambitions and constraints we tentatively selected the "California Water Project" as the focal point for the initial phase of our study.

Although many aspects of our initial study (dealing with the California Water Project) are continuing, we have recently undertaken a study of certain other phases also. Notable among these are studies by the Berkeley, Santa Barbara and Riverside campuses dealing with coastal resources and coastal phenomena. It has been pointed out to us by personnel of the California Resources Agency that approximately 80 percent of the people of California live in the Coastal Zone. This fact suggests that the many conflicting proposals for use of the resources in this zone might better be evaluated in the light of information derived through remote sensing studies such as ours.

In recent months, several of the training courses which have been taught by scientists from our multi-campus project have been attended

primarily by scientists from California's Administrative Branch who seek to learn how they can most effectively use data of the type which *ERTS and "high flight" imagery will provide, the better to manage* California's earth resources.

Additional activities recently engaged in by our group stem from our realization that implied above and expressed as follows: the providing of useful information about earth resources through the use of remote sensing techniques is, at best, a difficult task. In fact, it becomes an almost futile task if only one image of the area of interest is given in the completely unenhanced from, to one analyst, and he uses only one approach in attempting to extract information from it that might be of use to only one of the host of potential beneficiaries of such information. In contrast with this limited approach, there are several techniques available to an image analyst, each of which, we are finding, may add a small amount to his ability to improve the usefulness of resource information that he is attempting to provide. Furthermore, the overall usefulness of the final product may be improved far more than might be suggested merely by summing up the improvements made possible through individually employing these various techniques, as appropriate. Hence, at some point in the process a threshold is crossed, to the left of which the information acquired by remote sensing is virtually worthless and to the right of which it becomes progressively more useful, even to the point of becoming the most useful combination of tools and techniques available to those interested in achieving the wisest possible management of this globe's

:ritically limited complex of earth resources.

The foregoing considerations are reflected in the chapters which follow.

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Chapter 2

DEFINITION OF EARTH RESOURCE POLICY AND MANAGEMENT PROBLEMS IN CALIFORNIA

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2.1 INTRODUCTION

Under the Integrated Study, our Social Sciences Group has a number of objectives: (1) to ascertain the present functions and methods of operation of the various Divisions of the State Department of Agriculture; (2) to identify those which could ultimately utilize ERTS and other remote sensing data in performing their activities; (3) to determine in specific terms the "climate of acceptance" for remotely-sensed data; (4) to investigate and assess the user potential of ERTS as envisioned by resource managers in government; and (5) to study the ways in which data enter into the resource management decision process, the latter with a view to learning how data derived from remote sensors could affect and, perhaps, improve the process.

2.2 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

During the period under review, the Social Sciences Group has made significant progress toward accomplishing its goals as part of the Integrated ERTS Project. As was reported earlier, the California Department of Agriculture was selected as a potential beneficiary of ERTS data. This is consistent with the official statement of the National Academy of Sciences Committee on Remote Sensing for

Agricultural Purposes: "For resources to be managed wisely, there must be accurate and timely information, and remote sensing from aerospace platforms to provide quantitative data from which large amounts of needed information can be extracted. Much of this can be made available not only to responsible officials but to the public at large."*

The initial phases of the work took the form of a canvass of the various divisions of the State Department of Agriculture with interviews with key personnel. Entree and excellent working relationships were gained and established through the cooperation of Mr. Earl Davis, the State Coordinator of Remote Sensing, and the active participation of Dr. Gordon F. Snow, Acting Director of Agriculture for the State.

Our study, which began before the July, 1972 launching of ERTS, has established "ground truth" in the socio-political arena. In other words, we have become familiar with the terrain so as to be better prepared to observe the uses to which new data are put and, eventually, their effects. It can be noted, at the outset, that the official "climate of acceptance" in the State Department of Agriculture assures a ready welcome for ERTS data.

As early as 1937, under enabling legislation known as the California Marketing Act of 1937, aerial surveys were made of peach orchards as a means of carrying forward estimates of yields and production. Some of the very same government officials and industry representatives

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*National Research Council, National Academy of Sciences, Committee on Remote Sensing for Agricultural Purposes, Remote Sensing, with Special Reference to Agriculture and Forestry, 1970.

instrumental in these earlier efforts have now "graduated" to the conceptual level of ERTS. In the 1967-68 Biennial Report of the California Department of Agriculture, the Bureau of Agricultural Statistics, which operates jointly under State and Federal sponsorship, referred specifically to the use of aerial photography in determining fruit acreage inventories and indicated ongoing experimental work in the mapping of fruit and nut plantings in several countries.

W. Ward Henderson, Chief of the Bureau, suggested that in addition to the more obvious benefits that might possibly flow from ERTS and other remote sensors, information that would yield <u>earlier</u> and <u>more reliable</u> forecasts and estimates of production could have a profound effect on industry strategy and politics. By taking some of the guesswork out of the bargaining procedures between growers and processors, ERTS data might lessen tensions. Ultimately, refinement of crop estimation and, consequently, more efficient planning, with processors' risks lessened, could have a stabilizing effect on the bargaining and marketing processes. Mr. Henderson foresaw as a primary outcome a clearcut benefit to the consumer of agricultural products.

While increasing competitive pressures in agriculture and continued emphasis on marketing have heightened the demand for improved statistical data, "the basic information is still obtained on a voluntary basis from farmers, stockmen, hatcheries, dealers, processors, warehousemen, transportation firms, merchants, marketing organizations, and others"*

*State of California, Biennial Report, 1967-1968, California Department of Agriculture, pp. 68-9.

identified with the State's agricultural industry, as well as from County Agricultural Commissioners. It is the view of an official in the Division of Marketing and Services that some of the main sources of current information cannot be relied on. Supplying the data is tedious and costly; if a marketing order were terminated with cessation of surplus control, the affected industry would probably curtail its reporting. If this were to occur, serious gaps would develop in the data. Against such a contingency, the repetitive and continuous aspects of ERTS reporting offered a promising antidote. Moreover, the advantages of continuous reporting become clear when one observes the long-range effects of orderly planning in the production of food. From the orchard to the grocery basket, every step in the chain is in a dependent sequence, and miscalculations and poor synchronization are costly. It might well be that the ultimate beneficiary of ERTS data, intelligently utilized, would be the consuming public.

The Bureau of Plant Industry, especially in both its Control and Eradication and its Exclusion and Detection Divisions, has a long history of interest in remote sensing techniques. Dr. Gordon F. Snow, Special Assistant to the Director of Agriculture, prepared a proposal three years ago for the use of remote sensing capability in detecting plant diseases, specifically, yellow leaf roll virus in peach and nectarine trees and branched broomrape in tomato plants. The Bureau of Plant Industry is especially concerned with the uses of ERTS. In fact, the staff assistant to the State Coordinator of Remote Sensing, is a plant pathologist (Dr. David Adams), formerly with that Bureau. Dr. Adams works closely with members of our Integrated ERTS project,

notably with the Remote Sensing Laboratory and with the Social Sciences Group. He anticipates that the survey work eventually accomplished through remote sensing will be cheaper and better than that now achieved through field work and that, through this change of orientation, specialists will be released for more important analytical tasks. At present, Dr. Adams is developing an experimental control project on a virus problem in the Ventura citrus groves. Both the University of California Remote Sensing Laboratory and the NASA-Ames Research Center have been consulted, since there appears to be the prospect for a combination of ERTS and U2 low flight photography. With grower associations having evinced interest in the project, this experiment could provide a useful model for genuine integration of activity at all levels, from NASA through to the public.

As background for the data utility assessment that at some appropriate later date must be made, we have gathered research materials on the uses of ERTS by other experimenting groups and at other sites. In the available reports, there seems to be considerable preoccupation with technical details, e.g., equipment for data analysis and arrangements for ground reconnaissance. "Progress" is limited to the acquiring of personnel or assigning of tasks. The situation in California seems considerably more advanced. Favored by nature, California produces on a commerical basis some 200 agricultural products, under tremendously varying conditions -- from North to South, and from high to low elevations, with extremes of temperature. With agriculture its foremost industry, the State's Department of Agriculture is a highly respected body with a long history of high

professional standards. From the view of high level policy as it pertains the State, reference should be made to the State Board of Agriculture, which is appointed by the Governor as advisory to him. The chairman of this Board is an ex officio member of the University of California Board of Regents. These details are provided as an indication of the State of California's explicit recognition of the importance of its agriculture and, for our specific and proximate purposes, as the structure with and within which we are working in our ERTS endeavors.

Not surprisingly, in view of California's sophistication in matters agricultural and because of its history with respect to remote sensing, we have encountered considerable interest in ERTS, as well as a substantial degree of open-mindedness on the part of potential users. If there exist the traditional bureaucratic resistance and recalcitrance toward innovation, there is no evidence to that effect at this early stage. What seems to be imminent, however, is the danger of an oversell created by a small sector of enthusiasts whose optimism has caused them to overlook the enormous gap between ERTS imagery and usable information. The disparity between the confident speeches and treatises about ERTS and related technologies as likely instruments for revolutionizing the management of plant, soil, and water resources and the reality, i.e., "ground truth," becomes dramatically evident when one moves out of the laboratory and into the field. While there is high-level preoccupation with the technology of remote sensing and considerable advance in the state-of-the-art, little attention has been paid to the mechanisms by which ERTS data could be moved into channels readily accessible to

users. That this is not exclusively a California problem but rather, one that characterizes the ERTS program is suggested in the State of Ohio report (July 1972).*

There, problems arose at the very elementary level because of the need by certain individuals for precise information as to when the spacecraft would pass over specific areas in Ohio. In California, no such lack exists. Considerable publicity has been given to ERTS activities and to the likely benefits to be derived from them. But there exist no direct channels for disseminating information to the potential user. The connection between the scientific experimentation and the users of ERTS data usually is poorly defined or nonexistent. For example, the U.S. Department of Agriculture issued a news bulletin (May 26, 1972)** that hailed the launching of ERTS-A as "an important step in helping agricultural scientists develop better technology to manage plant, soil, and water resources." Then follows a description of ERTS: "ERTS-A will gather information on vegetation, soil, and water faster than it can be gathered with aircraft or ground observations." The four experiments by the Agricultural Research Science are then described. The bulletin then concludes with these words: "No one can accurately assess the value of remote sensing for world agriculture. It is estimated that in the United States alone, fire, insects, and disease cause $13 to $20 billion in losses annually. Early detection of

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*State of Ohio, Department of Development, Relevance of ERTS to the State of Ohio, N72-29273, July 1972.

**U.S. Department of Agriculture, News, USDA-1783-72.

these enemies could provide for more timely application of effective control measures and thereby reduce the magnitude of losses." These noble generalizations fail to recognize the ground truth. In California, for example, the channels by which ERTS information can be disseminated have not yet been clearly defined, nor have the bureaucratic mechanisms that can expedite the process of information transfer.

Our research leads us to believe that information dissemination, as conceived by the architects of the ERTS program, does not officially include users at all. The data flow stops with the Principal Investigators, who are not users, but in the final analysis, technical middle men. While these people play an important role, the real test of ERTS lies beyond them, in an unstructured, unmapped no man's land. Here exist the users, whose experience should, optimally, provide NASA with feedback to guide the evolution of future satellite systems. If ERTS is to achieve its promise, it will be through the activities of the <u>users</u>, be they government agencies, grower groups, or private individuals, and not the technical specialists.

In this respect, the conclusion of an OECD Working Group of Scientific and Technical Information are pertinent:

> The effectiveness of human activities can only be assessed on the basis of a complete chain of events, which passes from scientific knowledge and its creation, through the stages of technical research and through many many complex decisions, to the production of goods or service, integrated into an economic and political system. Exchange of knowledge is needed within each group of men concerned at each stage of this chain;

it may need translating into another "language" for transfer to other groups engaged in other tasks.*

The Working Group concluded that the spectacular success of development in Japan was due in large part to the "efficiency of their knowledge transfer mechanisms."

For us who are observing at first hand growing sophistication in the acquiring and storing of information but a dearth of skill in implementing its full utilization, these findings have special import. Our contacts with a large number of government agencies reveal the problem of information management, in the sense of interpretation, transfer, dissemination, and utilization, as crucial to the ultimate success of and support for ERTS. It is for this reason that we state our research findings, even at this relatively early stage, in such emphatic terms. We are convinced that the communication lack is a severe deficiency in the overall ERTS program and, in fact, have devoted some of our efforts to ascertaining the ways in which ERTS data could ultimately be put into public service. Besides our work with government agencies, we have begun making contact with grower associations. We have learned that they might be a potent force in getting certain Divisions of the State Department of Agriculture to take a more active role in acquiring and using ERTS data. Our primary contact to date has been with the California Canning Peach Association. At a meeting with that group on December 1, Professor Robert N. Colwell, Principal Investigator of the Integrated Project made a presentation about ERTS technology, its potential, and its limitations. Dr. Ida R. Hoos, of the Social Sciences Group, pointed out how the farm organizations and commodity groups

*Organization for Economic Cooperation and Development, Information for a Changing Society, Some Policy Considerations, Paris, 1971, p. 13.

could serve as an important medium of information exchange and communication. In the discussion which followed these presentations, members of the Association showed genuine enthusiasm for accepting these new technological developments, but considerable mystification as to how they might put such developments to practical use. One of the most promising applications appears to be that of minimizing early spring frost damage to peach orchards by using ERTS-1 data to help monitor the soil moisture status of each orchard. If the soil moisture is maintained above a certain level, the likelihood of forest damage is greatly reduced. The stage was set in this first meeting for many profitable discussions at future meetings, both with this and with several other "grower" groups.

2.3 PROPOSED FUTURE WORK

Building on the review that we have made of the respective Divisions of the State Department of Agriculture, our Social Sciences Group intends to explore further the specific ways in which these government bodies have used or conceive that they can in the future use ERTS data. Herein lies the way that the technology of remote sensing can be assessed in realistic terms. Since putting the technology to useful work is one of NASA's basic goals, this research is both goal- and action-oriented. The State of California, with its enormous variety of products and diversity of growing conditions, has provided an appropriate test site. Observations relative to uses which can be made of ERTS-1 imagery, in all its manifestations and ramifications, can provide lessons in the immediate applicability not only throughout the United States but in other countries as well. Some agencies in the State of California have begun, through the University of California's

Remote Sensing Laboratory and with the active participation of its technical specialists, to experiment with ERTS imagery as a source of information to help them carry out their functions. How this information is put to use within State Government and its real and anticipated effects on decision-making processes with respect to resource management will be studied and reported.

We plan also to carry forward the work we have begun with farm organizations. Because they traditionally have served as a vehicle or channel through which information is delivered to the farmers and growers, they must be recognized as a vital link in the communications chain between ERTS and the ultimate consumer. We want to ascertain whether and how ERTS data can become a useful input in the California State Department of Agriculture's functioning and, moreover, in the farmer's production function. We expect, further, to learn, through experimentation now underway, whether aerial photography might serve a more immediate need. The greater resolution available through high altitude flights, as compared with satellite imagery, might yield more useful results, at least in certain types of agricultural survey work.

To assess the advantages and disadvantages, benefits and shortcomings of remote sensing-derived data, we will continue our field studies of the State Department of Agriculture and of the grower associations most likely to be responsive to new management modes and to new sources of information -- ERTS and aerial. As before, we will continue to cooperate with the State's Coordinator of Remote Sensing, Mr. Earl Davis, and with his assistant, Dr. David Adams. As always, we will draw upon the technical expertness of

the Remote Sensing Laboratory at the University of California and will, wherever appropriate, work in conjunction with the specialists from the various campuses.

We observed earlier that there is a marked discrepancy between the attention being paid to the technical aspects of ERTS and the interest in exploring applicability and testing utilization. This has contributed to a wide gap between the technological sophistication of ERTS and the capability of socioeconomic mechanisms to receive and use the data, even if only on a trial basis. While the resulting mismatch might be expected and accepted at early stages of ERTS, its persistence could be detrimental to its objectives as stated by Mr. Charles W. Mathews at the time of the ERTS launching. These objectives were user-oriented. Our intention, therefore, is to move forward in the attempt to link the users into the communications chain. Connecting the observing capability of earth resources satellite and other remote sensing technologies to the nation's food producers constitutes an important step in assuring the success of and public support for NASA's efforts. This is a matter which the Social Sciences Group will continue to explore and, wherever possible, implement.

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Chapter 3

USER REQUIREMENTS FOR THE APPLICATION OF REMOTE SENSING IN THE PLANNING AND MANAGEMENT OF WATER RESOURCE SYSTEMS

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3.1 INTRODUCTION

The course of this investigation toward use of remote sensing as a new tool in the routine activities of water resource planning and management groups in many private and public entities has followed a three-stage development. As reported in two previous annual summaries and progress statements, users' needs for hydrologic information were determined and classified into categories under headings listed as components of the "runoff cycle".

Secondly, these components were identified as subsystems of a generalized hydrologic system. The elements were then resolved into two classes of informational needs; namely, operational parameters, and specialized parameters for research and development. The former class has a broader and possibly synoptic character in comparison with the latter and, in many instances, represents the kind and form of information most necessary for direct application to large scale resource operations as well as to planning functions.

Within the parameterization framework, the resolution, frequency, type and form of data were outlined, and a sample of standard methodology in current usage was noted. And finally, the "state of the art" method and spectral region for remote sensing of the parameter was suggested.

This third phase of the study deals with the application of remote sensing to the solution of problems of planning and management of water resource systems.

The objective herein is to devise the means and methods whereby a new data source (remote sensing) may be incorporated into existing operational procedures currently in use by management agencies concerned with hydrologic and water resource systems. Alternatively, the necessity of generating new approaches for the application of remotely sensed data is anticipated for certain functions not adaptable to the new technology.

Progress in this phase is seemingly more deliberate, seeking to find applications where most rapid implementation can be affected to demonstrate the utility of the technology.

3.2 WORK PERFORMED DURING PERIOD COVERED BY THIS REPORT

Three areas of hydrologic applications have been defined for this period, scoped to be compatible with other efforts in connection with the Earth Resources Technology Satellite research concurrently under study by this project team.

Availability of the multilevel data platforms afforded by low-flight aircraft, with ground measurements made concurrently; high-flight imagery (U-2) both pre- and post-ERTS launch; and the multispectral 4 channels scanner imagery produced by ERTS-1, on a repetitive 18-day cycle permiting some comparative assessment.

This data is acquired for a series of specific targets in the Central California Region defined as the Delta Test Site, with some peripheral input from scans made in adjacent areas of high mountains and in the San Francisco Bay Area and North Coastal Region.

Among many possible user needs, which have been considered, several have been selected for initial evaluation. Examples presented are typical operational tasks of water resource managers. These illustrations reflect areas of progress principally because of the concurrent efforts being made by the project team in analysis and utilization of the ERTS-I imagery.

Sample studies include three common to our ERTS-I research work, as well as for proposed skylab application:

1. Gross water quality changes in deltaic regions,

2. Optimization of multiple-use management of large water resource systems,

3. Prediction of snowpack water yields from high mountain regions.

Progress has been made in the first two subjects. Work on snow, which is cooperative with the staff of the FRSL (Berkeley) has been limited pending receipt of winter season data now being acquired and distributed.

3.2.1 Water Quality and Water Resource Systems Application

Significant progress in monitoring certain water quality constituents in both natural and man-made water bodies like lakes, reservoirs and river systems has been made in the initial testing of satellite data capabilities. Three additional levels of image platforms were used in conjunction with the ground truth work to select the image format, define the spectral bands, and to select optimum target sites for various quality conditions.

Figure 3.1 depicts the general area of the investigation and denotes fifteen specific target areas, subject to future amendment. Intensive efforts were made at the site of the confluence of the Sacramento and American Rivers in Sacramento, California and in the Lake Berryessa area.

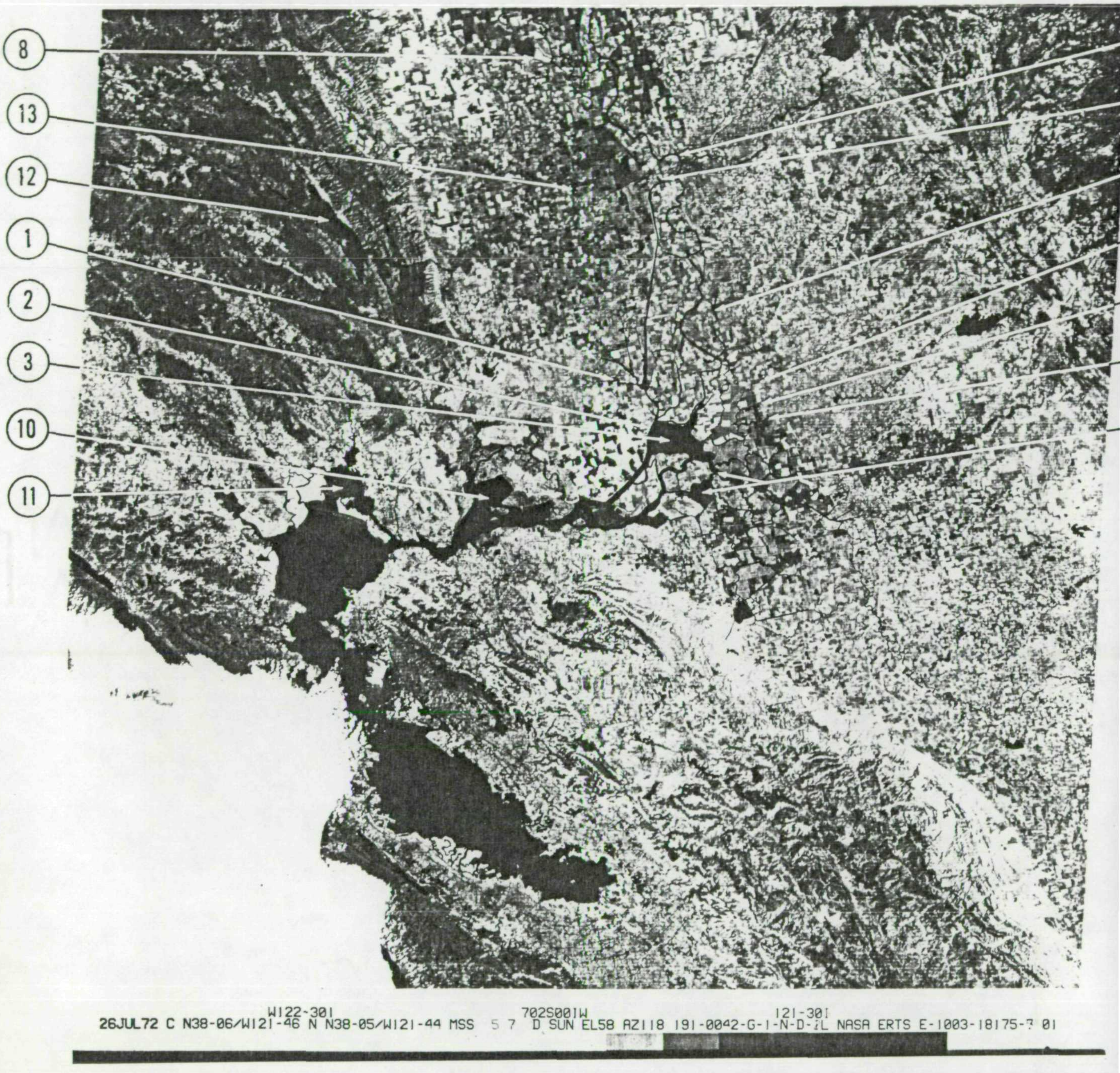

Figure 3.1. Selected study areas in San Francisco Bay and Sacramento-San Joaquin River Delta Test Sites.

Clear Lake and Folsom Lake are also being included in the reservoir systems being monitored. The identification of the numbered sites is presented in Table 3.1.

Discussions have been held with the agencies (local, state and federal) principally responsible for conduct of ongoing water quality field monitoring programs for the sites and tentative arrangements for early access to data acquired have been made.

Agencies include the California Department of Water Resources and the U.S. Bureau of Reclamation who jointly operate the Delta Water Quality Monitoring Program, both in-house and via contracted services. Other local sources for specific areas have been used. Supplementation of these data by project personnel in a regular field measurement program for the primary sites has been made operational on a bi-weekly (or more often) basis consistent with weather phenomena and to verify seasonal changes associated with physical and biological characteristics of the water bodies.

Table 3.2 presents a summary assessment of the water quality and important physical parameters of interest to water resource management as potentially capable of definition by remote sensing.

Table 3.1 Selected Study Areas

Sacramento - San Joaquin River Delta Region, California

1. Lindsey Slough
2. Sacramento River near Rio Vista
3. Andrus Island (Brannan Island)
4. Beaver Slough
5. Hog Slough
6. Sycamore Slough
7. Frank's Tract

Other Sites

8. Colusa Basin Drain into Sacramento River
9. Discovery Park (Confluence of American & Sacramento Rivers at Sacramento)
10. Suisun Bay
11. San Pablo Bay (Salt concentration ponds)
12. Lake Berryessa
13. Davis - Municipal Sewage Stabilization Ponds
14. Lake Washington (Port of Sacramento)
15. Stone Lake

3.2.2 Snowpack and Water Yields

Consultation with the California Department of Water Resources staff on snow measurements and procedures currently in use has produced the format for prediction of water yield from snow in storage. The adaptation of remote sensing data acquisition into this prediction procedure is being studied by graduate students in hydrologic analysis in the Department of Civil Engineering under the direction of this project leader. This work will be completed in the current grant period and will be reported in the forthcoming annual report in May, 1973.

TABLE 3.2 EVALUATION OF SELECTED STUDY AREAS

HYDROLOGIC PARAMETERS	SELECTED STUDY AREAS: Lindsey Slough 1	Sacto. R.- Rio Vista 2	Andrus Is. 3	Beaver, Hog, Sycamore S. 4,5,6	Frank's Tract 7	Colusa Basin Drain 8	Discovery Park 9	Suisun Bay 10	S.P. Bay Ponds 11	Lake Berryessa 12	Davis Ponds 13	Lake Washington 14	Stone Lake 15
Stream Morphology	X			X		X	X	X					
Surface Velocity & Direction		X		X	X		X	X					
Stream Stage-Discharge	⊗	X		X		X	X						
Turbidity-Suspended Sediment	⊗	⊗	X	X	X	X	X	⊗	X	⊗	X	X	X
Hydrocarbon Surface Films		X	X		X		X	X					
Water Chemistry	⊗	X	X	X	X	X	⊗	X	⊗		X		
Surface Temperature	X	X	X	X	X	X	X	X	X	X	X	X	
Surface Dissolved Oxygen	X	X	X	X	⊗	X	X	X		X	X	X	
Phytoplankton Density	X	X	X	X	⊗	X	X	⊗	X	⊗	⊗	X	⊗
Riparian Vegetation	X	X		⊗	X	X	X	X	X	X	X		
Lake Surface Area					X					X			X
Lake Depth					X					X	X	X	X
Change in Storage			⊗							⊗			X
Watershed Delineation	X			X		⊗				X			X
Watershed Topography	X			X		X				X			X
Vegetation-Type & Coverage	X		X	X		X	X	X		X			X
Land Use	X	X	⊗	X	X	X	X	X	X	X		X	X

X Look for parameter at selected study area

⊗ Important parameter at selected study area

3.3 FUTURE PROPOSED WORK

Continuation of the studies of application of remotely sensed hydrologic data for water resource management and operation is proposed for ongoing research under this NASA Grant.

Imagery provided by the several instrument platforms now operating is yielding the basic information which may be applied to a variety of user tasks. The interpretation, enhancement and utilization of much of the satellite data now being collected will continue to be directly useful for such application. Substantial time lag is inherent in the processes now used to collect, process and distribute imagery from all the sources. Thus, the information acquired late in the life of ERTS-l and the complementary high-flight programs will first become available at the investigator level mid-way of the following year, that is, in late 1973.

A very high potential for effectively enhancing satellite imagery for water resource application is being demonstrated by fellow researchers in this project. The techniques which have been devised give the capability for greatly extending the use of remotely sensed data in both hydrologic work, water quality assessment and in management.

Sequential coverage with multispectral images over time spans of more than one season are expected to permit a wider range of verification of potential uses. Additionally, the multilevel data provided by the current programs will benefit the analysis.

Recent periods of discussion and consultation with several direct user groups suggests that analysis and testing of applicability of remote sensing on real time problems will serve a dual purpose of demonstrating the utility of this technology in a very practical way and will further

permit a significant opportunity to work with the user group in a combined developmental and training mode. Since future users must be trained to recognize the potential capability of remote sensing technology and to seek new applications within their areas of specialization, this approach is proposed as an expedient to those ends. Cooperation of user teams is assured and interest is great on the subjects currently under study. Other remote sensing applications are being explored and, as noted previously, the use of enhancement techniques will clearly permit supplemental uses of the data beyond those presently recognized.

In summary, it is proposed to continue this investigation on the application of remote sensing to hydrologic and water resource management tasks in a direct cooperative mode with selected user groups of interest, who will make available ground truth information from present sources. Imagery currently available will be used intensively and additional sources may be added when available.

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Chapter 4

REMOTE SENSING DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA

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William C. Draeger, Paul F. Krumpe, Donald T. Lauer,
James D. Nichols, Howard O. Thrall, Randall W. Thomas
Sharon L. Wall
Forestry Remote Sensing Laboratory, Berkeley Campus

4.1 INTRODUCTION

During this funding period, two major studies are being carried out in northern California, namely:

1. Measurement of hydrologic resource parameters through the use of spacecraft and aircraft data in the Feather River Watershed area (see Figure 4.1).

2. Analysis of the Northern Coastal Zone Environment with the aid of spacecraft and aircraft data (see Figure 4.2).

A complete explanation of the study objectives, the relationships between these objectives and certain previous studies, and the results of the first two years of research can be found in Chapter 4 of the May, 1971 and May, 1972 Annual Progress Reports for the Integrated Study. The following introductory text provides only brief information on research objectives and background for each of the studies and the approach being used by the Forestry Remote Sensing Laboratory. In addition, recent activities relating to interchange and coordination between FRSL personnel and user agency resource management specialists are discussed.

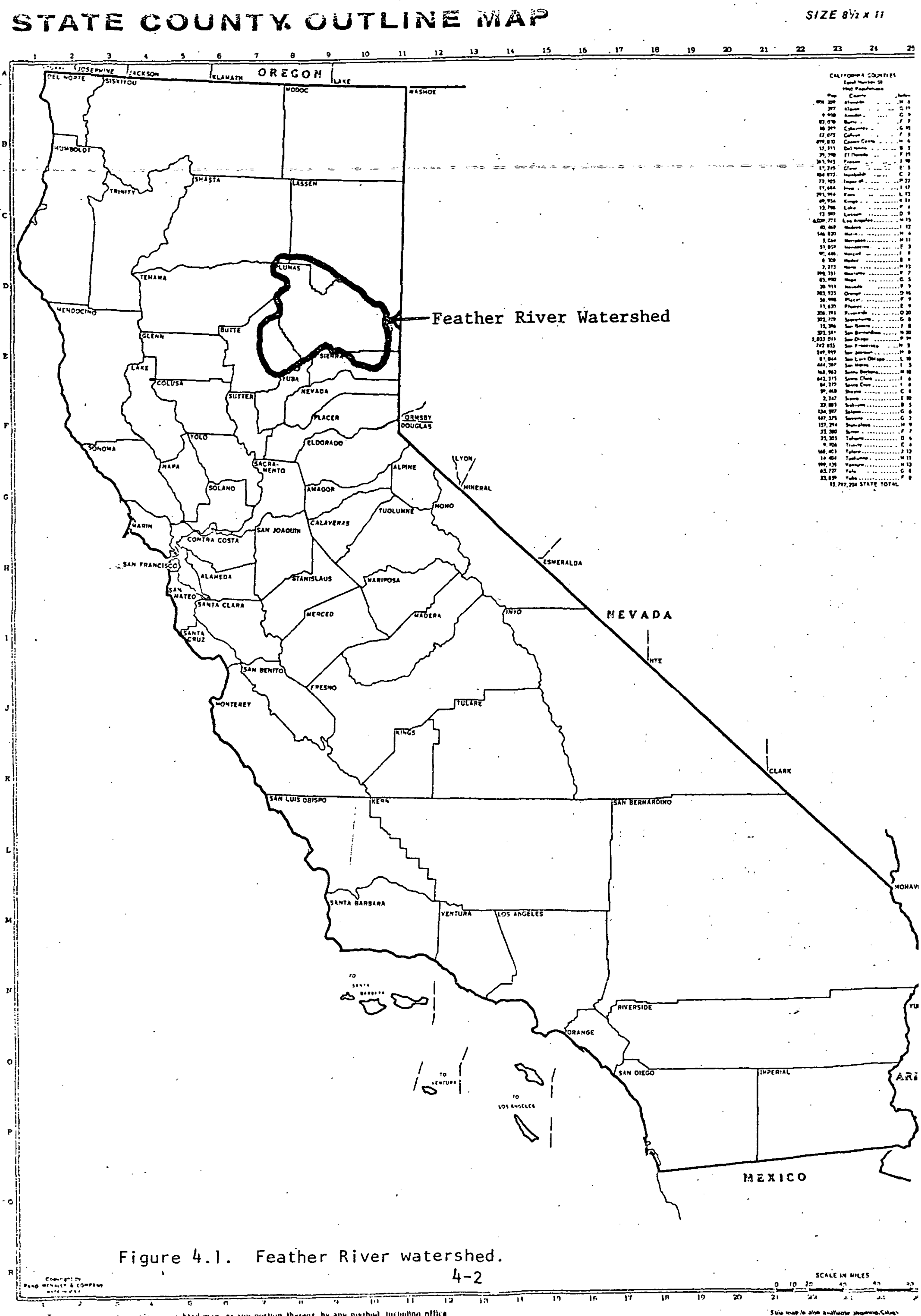


Figure 4.1. Feather River watershed.

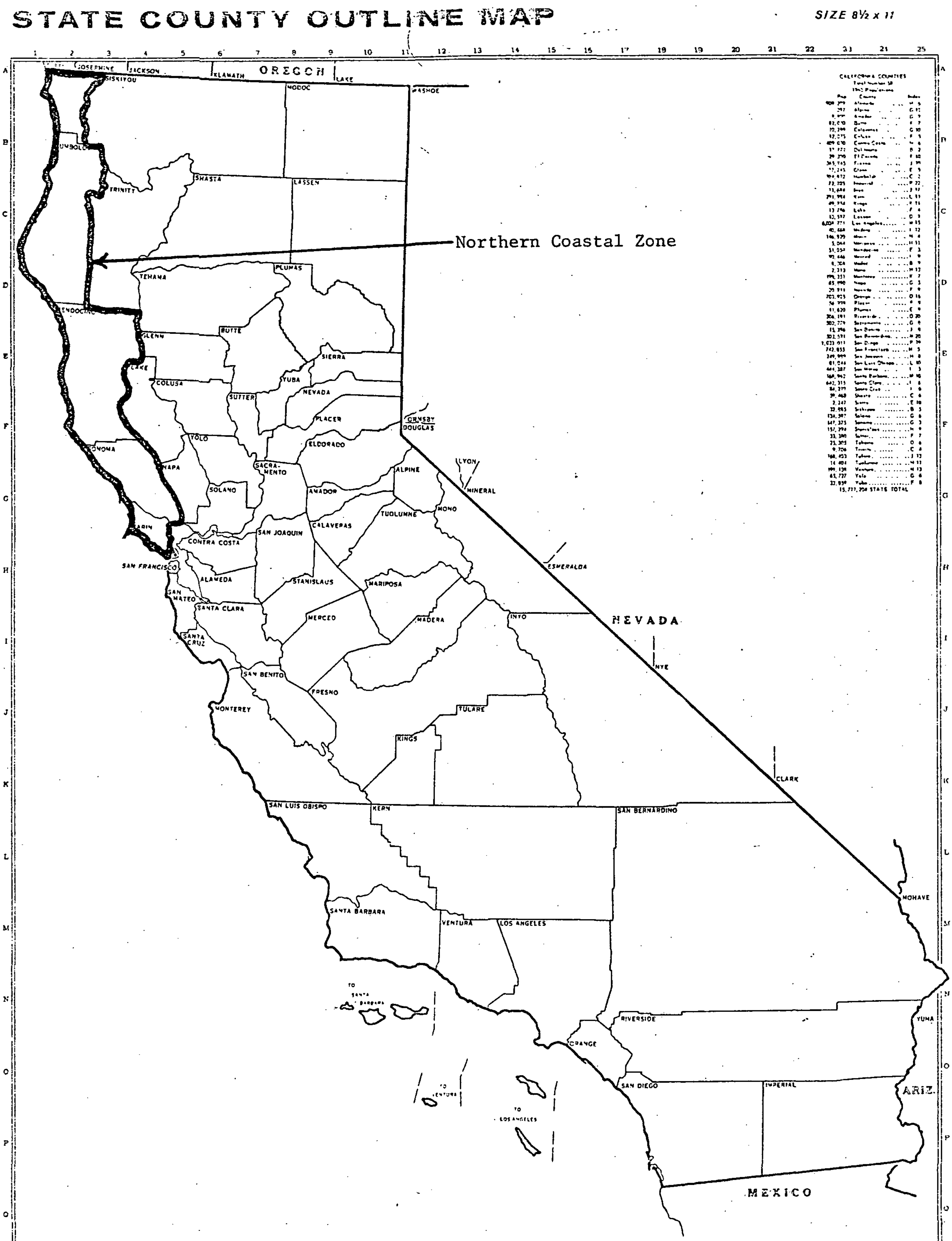


Figure 4.2. Northern coastal zone of California.

The body of this chapter is divided into two parts -- one for each of the studies listed above. Specific study objectives, work performed during this past funding period and future proposed work are documented.

4.1.1 Objectives

The primary objective of the work being conducted within the Feather River Watershed is to assess the usefulness of remote sensing techniques for acquiring natural resource information of importance to resource specialists and wildland managers, especially those responsible for the water resource. Efforts have been concentrated on examining certain physical parameters, important in terms of hydrologic phenomena, for which information is sought and used, and might be used more frequently in the future if one could demonstrate that it could be quickly and cheaply gathered. Thus, emphasis is being placed on ascertaining the relative interpretability of various types of remote sensing imagery for detecting, identifying, delineating, evaluating and monitoring the general management zones, vegetation/terrain types and vegetation density classes, geology-soils types, and snowpack conditions. An essential element of the work is to determine, in a quantitative fashion whenever possible, levels of accuracy, timing and costs associated with acquiring wildland resource information using methods of remote sensing, as compared to more conventional information gathering techniques.

The primary objective of the work being done within the Northern Coastal Zone is to evaluate the usefulness of remote sensing data in providing general land-use planning information. In particular, attempts

are being made to enumerate those physical parameters of the landscape which can be mapped with the aid of remote sensing data and which are of particular importance in determining the potential of an area in terms of land use, be it natural resource utilization, urban development or industrial development. This determination is being made with a consideration of the needs of planners now involved in the formulation of long range land use plans. The results of the experiment, therefore, are being evaluated in terms of the information requirements of those agencies actually responsible for the formulation of land use plans in the north coastal region.

4.1.2 Background

The Feather River Watershed and the Northern Coastal Zone areas possess a number of characteristics which enhance their value as test sites for this integrated study.

The California State Water Project is one of the most extensive and ambitious water resource developments ever attempted. The source of water for this vast project is the Feather River headwaters region, which drains into Lake Oroville, the keystone of the project in terms of flood control and regulation of downstream water delivery. Thus, the Feather River is an important component of an actual resource development operation. As such, conclusions which are reached regarding the utility of remote sensing data can be evaluated not only on a purely theoretical basis, but also on decisions that have been made, and in comparison to conventional techniques which have been and are being used to gather needed data. In addition to its importance in the California

Water Project, the Feather River area contains an extensive system of hydroelectric reservoirs which are operated by a public utility company in conjunction with the state water project facilities.

Most of the actual watershed lands of the Feather River region are administered by the U.S. Forest Service, which is charged with the responsibility of multiple-use management of the resources of the area. Although water storage and power-generation facilities have been highly developed, in many cases the management of the actual watershed lands themselves (to provide an optimum mix of resources including wood, livestock forage, recreational opportunities, fish and wildlife, and water) is not currently highly advanced. This is due primarily to an incomplete understanding of the complex man-resource interaction, and a lack of basic data regarding the physical parameters of the vast, wild, and poorly accessible areas involved. Thus, an opportunity exists not only to compare remote sensing techniques against conventional methods of data acquisition, but in many cases to evaluate the potential for providing information that is currently unavailable in the form or with the degree of accuracy, necessary to permit the development of a highly sophisticated broad-scale resource management system.

Likewise, it is becoming increasingly apparent that the Northern Coastal Zone of California is in itself an important resource. As population increases, the coastal zone will come under mounting pressure for development, both as a place of human habitation and as a place for more intensive use and development of natural resources. From San Francisco southward, the coast is already the site of numerous urban centers,

and the problem of planning entails not only how to plan for future development, but also how to deal with currently existing development. In many ways the northern coastal region presents somewhat different problems. In general the north coast (consisting of the counties of Marin, Sonoma, Mendocino, Humboldt, and Del Norte) is relatively rural, with an economy based on agriculture, timber, commercial fishing, and tourism. However, it is expected that intensive resource use resulting from increasing population will soon become a serious problem unless wise land use planning is undertaken. Thus the north coastal zone presents an excellent opportunity for intelligent, informed planning of development before intensive land use activities become widespread.

One prerequisite of intelligent land use planning of any region is a detailed and comprehensive knowledge as to the environment of the area in terms of its effect on potential resource management and use. In the north coastal area, one urgently needed type of information is an integrated inventory and evaluation of the physical characteristics of the region as they relate to the suitability for various types of land use. Since the bulk of the region can be classified as essentially wild land, it is particularly well suited to investigations of the ways in which remote sensing and other supporting data may be used in conducting such potential land use evaluations.

4.1.3 Apprcach

Our experience to date has convinced us of the necessity to use a systems concept and team approach in solving problems of interest to the earth resource manager. Consequently, the Forestry Remote Sensing

Laboratory has been organized to include five functional units (see Figure 4.3). These units address themselves to the most important problems which must be solved if a remote sensing system is to be employed successfully for earth resources inventory purposes. The five problem areas investigated under this team approach are as follows:

1. Determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

2. Definition of the spectral characteristics of earth resources and the optimum procedures for calibrating multispectral remote sensing data acquired of those resources;

3. Determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery either in its original form or when enhanced by various means;

4. Determination of the extent to which automatic data handling and processing equipment can extract useful earth resources information from remote sensing data; and

5. Effective dissemination of remote sensing results through the offering of various kinds of training programs in which the interaction between users and scientists can be emphasized.

The Operational Feasibility Unit, Image Interpretation and Enhancement Unit and the Automatic Image Classification and Data Processing Unit are the most active units on the Integrated Project, and a major part of the introductory section in Chapter 4 of the December 1972 Semi-annual Progress Report was devoted to explaining the procedures used by

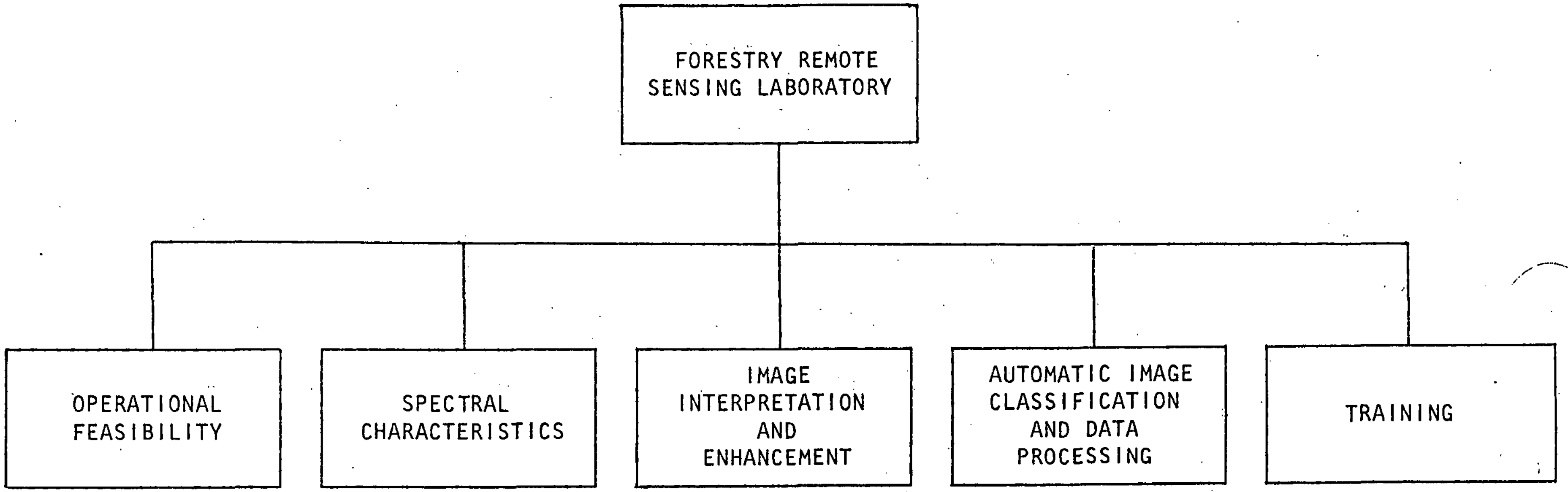


Figure 4.3. Organizational diagram of the Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

these units.

4.1.4 Interchange and Coordination with "User" Agencies

Efforts are continuing to better define "user requirements" and to further identify user agencies and key personnel who are keenly interested in the results of the remote sensing experiments being conducted in the Integrated Study. Specifically, additional information is being gathered about operational resource inventory projects which are currently in progress or have been done in the past within the Feather River watershed and northern coastal zone. To facilitate gathering these kinds of information, the Forestry Remote Sensing Laboratory held a 3-day workshop on the Berkeley campus in March 1973. Practicing wildland managers representing federal, state and private interests were invited to attend the workshop. The names of those persons who attended the workshop are given in Table 4.1.

The workshop provided an opportunity for (1) the resources specialists to become familiar with past project results and with preliminary results describing the utility of ERTS-1 data and high altitude aerial photography, and (2) the FRSL staff to thoroughly define and evaluate a multitude of practical wildland resource management problems. The workshop was presented in three parts -- one day in the lecture room on the fundamentals of remote sensing data acquisition and data analysis; one day in the field with ERTS-1 and high flight images in hand; and one day in the laboratory on solving practical problems with the aid of remote sensing data (see Figure 4.4).

TABLE 4.1. PARTICIPANTS IN A WORKSHOP ON AIRCRAFT AND SPACECRAFT REMOTE SENSING OF FOREST LANDS

Federal Government Personnel

Paul F. Barker, Los Padres National Forest, U.S. Forest Service
Harry L. Bowlin, California Regional Office, U.S. Forest Service
DeLoy H. Esplin, California Regional Office, U.S. Forest Service
Robroy A. MacGregor, Tahoe National Forest, U.S. Forest Service
Neil McDougald, Sequoia National Forest, U.S. Forest Service
Paul T. Meiscke, Mendocino National Forest, U.S. Forest Service
John Mooneham, Sequoia National Forest, U.S. Forest Service
Bruce Moyle, Six Rivers National Forest, U.S. Forest Service

State Government Personnel

Frank F. Franklin, Sacramento Office, California Division of Forestry
John R. Edwards, Department of National Resources, State of Washington
Fred D. Imhoff, Monterey Office, California Division of Forestry
Edwin E. Sechrist, Jr., Sacramento Office, California Division of Forestry
Robert W. Weaver, Sacramento Office, California Division of Forestry

Private Industrial Personnel

Thomas Berry, Natural Resources Management Corporation
Charley G. Evers, Simpson Timber Company
Daniel P. Gaut; Hammon, Jensen, Wallen & Associates
Robert Maben, American Forest Products Corporation
Glenn More, Kimberly Clark Corporation
E. R. Pratt; Hammon, Jensen, Wallen & Associates
John C. Pricer, American Forest Products Corporation
Douglas V. Whiteley, Soper-Wheeler Company
Everett B. Wycoff, Crown Zellerbach Corporation

Other Personnel

Allan Legge, University of Calgary, Alberta, Canada
Ken Nishioka, Ames Research Center, National Aeronautics & Space Administration

Figure 4.4. A group of 25 practicing resource specialists responsible for managing federal, state and private lands in northern California attended a 3-day workshop presented by Forestry Remote Sensing Laboratory personnel. A principal purpose of the workshop was to evaluate, with assistance from the participants, practical resources inventory and monitoring problems which possibly could be solved with the aid of state-of-the-art remote sensing techniques. The top photo shows the group studying imagery while visiting the San Pablo Reservoir study area located near the Berkeley campus. The bottom photo shows the group engaged in a laboratory exercise designed to test the usefulness of imagery for purposes of classifying forestlands.

4.2 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

4.2.1 Analysis Within the Feather River Watershed

4.2.1.1 Introduction

Work within the 2.5 million acre Feather River Watershed region is centered on two topics -- vegetation/terrain mapping and snow surveys. Table 4.2 lists several of the user agency groups which are keenly interested in the results of this research.

4.2.1.2 Vegetation/Terrain Mapping

The approach to wildland vegetation/terrain mapping with the aid of ERTS-1 imagery emphasizes the following objectives: (1) the acquisition of ground control data, (2) a feasibility analysis relating to the detection and identification of resource types, (3) the development of interpretation aids and related resource descriptors, (4) the quantitative testing of manual interpretation procedures in the detection and classification of landscape elements, and (5) the determination of cost-time factors relating to mapping resources using various interpretation techniques.

Acquisition of Ground Control Data by Interpretation of High Altitude Aircraft Color Infrared (CIR) Photography

More than 90 percent of the Feather River drainage basin has been mapped to date utilizing high altitude aircraft CIR imagery. Approximately thirty wildland resource entities among seven landscape categories are being classified (see Table 4.3). Using this classification scheme, a vegetation/terrain resource map (see Figure 4.5) is being produced and field checked and is serving as ground controlled data,

TABLE 4.2. USER AGENCY GROUPS COOPERATING

ON THE INTEGRATED STUDY -- FEATHER RIVER WATERSHED REGION

USER GROUP AGENCY	PERSONNEL CONTACTS	INFORMATION REQUIREMENTS/POTENTIAL REMOTE SENSING APPLICATION
CALIFORNIA REGION FRAMEWORK STUDY COMMISSION FOR SOUTHWEST INTER-AGENCY COMMITTEE: WATER RESOURCES COUNCIL	MR. JIM COOK (USFS) MR. LYLE KLUBBEN (USFS) MR. WILLIAM FRANK	REGIONAL VEGETATION/TERRAIN MAPPING LAND USE PRACTICES AND CHANGES LANDSLIDE AND STREAM SEDIMENTATION DETECTION
DEPARTMENT OF WATER RESOURCES, STATE OF CALIFORNIA	MR. G. SAWYER MR. A. DE RUTTE	SNOWPACK DETECTION HYDROLOGIC OUTPUT PREDICTIONS
CALIFORNIA COOPERATIVE SNOW SURVEY	MR. A. BROWN	SNOWPACK DETECTION AND HYDROLOGIC PREDICTIONS
CALIFORNIA DEPARTMENT OF CONSERVATION DIVISION OF FORESTRY	MR. T. ARVOLA MR. C. PHILLIPS MR. R. WEAVER	VEGETATION-SOILS INVENTORY FIRE DAMAGE APPRAISAL RANGELAND CONTROL BURNING MONITORING COMPLIANCE WITH FOREST PRACTICE ACT
U.S. FOREST SERVICE	MR. JIM MC LAUGHLIN	SOILS-TERRAIN ANALYSES
TAHOE REGIONAL PLANNING AGENCY	MR. JIM BRUNER	ENVIRONMENTAL CHANGE DETECTION SEDIMENT POLLUTION ANALYSIS LAND USE INVENTORY
CALIFORNIA STATE DEPARTMENT OF PARKS AND RECREATION	MR. GEORGE RACKELMANN MR. JOHN HAYNES MR. SANDY RABINOWITCH	LANSCAPE INVENTORY SITE LOCATION AND PLANNING

TABLE 4.3. CLASSIFICATION SCHEME FOR VEGETATION/TERRAIN RESOURCES WITHIN THE FEATHER RIVER WATERSHED REGION

FOREST RESOURCES

Coniferous Forests

A. High Elevation Red Fir Forest
B. Westside Intermediate Mountain Conifer
BB. Eastside Intermediate Mountain Mixed Conifer
C. Eastside Intermediate Pine-Scrub Forest
D. Eastside Northern Juniper Woodland
E. Eastside Timberland-Chaparral Complex

Hardwood Forests

F. Intermediate Mountain Xeric Hardwoods
G. Westside Foothill Pine-Oak Woodland
GG. Westside Foothill Oak Woodland-Grass
GC. Westside Foothill Oak Woodland-Chaparral
GGC. Westside Foothill Oak Woodland-Grass-Chaparral
H. Mixed Mesic Hardwood Communities
I. Westside Foothill Mixed Hardwood-Conifer Forest

NON-FOREST RESOURCES

Chaparral

J. Westside Valley Front Foothill Chaparral
K. Westside Intermediate Mountain Chaparral
KK. *Eastside Intermediate Mountain Chaparral*
L. Eastside Valley and Basin Front Sagebrush Scrub

Grassland-Meadow-Marshland Complex

M. Subalpine Grassland
N. Intermediate Interior Valley Xeric Grassland
O. Mesic Meadow Complex
P. Freshwater Marshland

AGRICULTURAL AND RANGELAND RESOURCES

Q. Mesic Cultivated Croplands
R. Mesic Rangeland
S. Xeric Eastside Grassland-Scrub Rangeland

OTHER LANDSCAPE FEATURES

T. *Forest Plantation Sites*
U. Urban-Residential-Commercial Sites
V. Exposed Soil
W. Exposed Bedrock

- WB. Basalt
- WA. Andesite
- WR. Rhyolite
- WP. Pyroclastics
- WG. Granite
- WU. Ultrabasics
- WS. Sedimentary
- WM. Metavolcanics

HYDROLOGIC RESOURCES

X. Standing Water
Y. Running Water
Z. Snowpack

VEGETATION-TERRAIN RESOURCES PERCENT COMPOSITION RANGE WITHIN HOMOGENEOUS DELINEATED AREAS

PERCENT COMPOSITION	CODE NUMBER
0 - 5	1
6 - 20	2
21 - 40	3
41 - 60	4
61 - 80	5
81 - 100	6

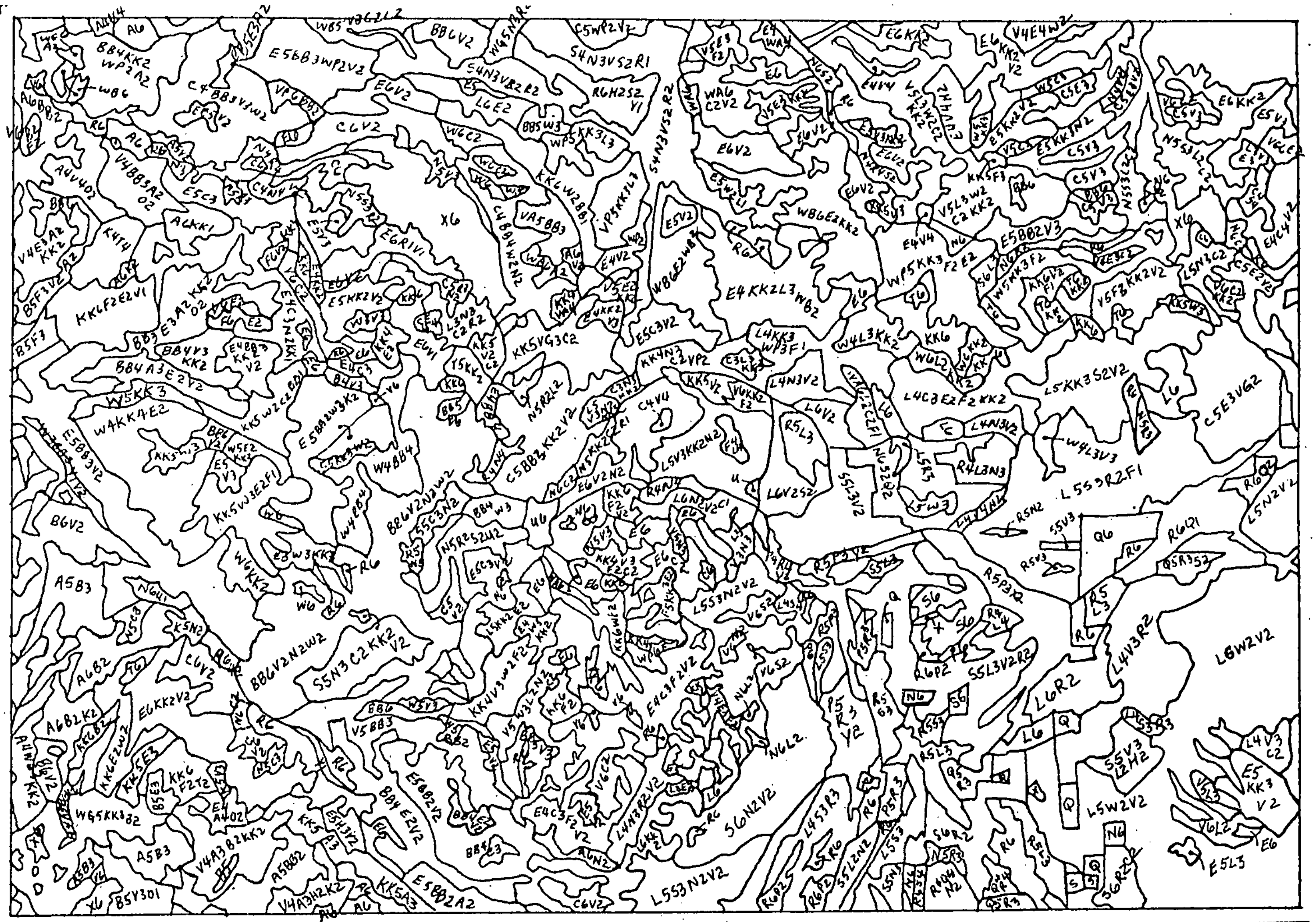


Figure 4.5. Classification of wildland resources within the Davis Lake intensive study area. Resource classification code numbers refer to percent composition of specific resources within delineated areas. The interpretation was accomplished using high altitude (1:120,000) false-color infrared transparencies. This map functions as ground controlled data, useful in ERTS-1 image analysis, and represents "state of the art" regional mapping. The area represented above is 403,000 acres, about one-sixth the entire Feather River watershed.

useful in ERTS-1 image analysis. Major landscape categories include (1) coniferous forests, (2) hardwood forests, (3) chaparral, (4) grassland-meadow marshland complex, (5) agricultural and rangeland resources, (6) other landscape features and (7) hydrologic resources. Elements within these categories have been classified by percentage composition within delineated type-areas where uniform color, tone, texture, vegetation density and/or composition are apparent on the imagery.

In addition to this ground controlled vegetation/terrain resource map, the following additional regional resource maps have been either prepared or acquired: (1) Lithologic Geology, (2) Mean Annual Precipitation, (3) Soil Series Complexes, (4) Elevational Zones, (5) Drainage Network (Strahler Stream Order System) and (6) an available vegetal cover type map (see Figure 4.6). This vegetal cover type map, prepared by the Comprehensive Framework Study California Region, is a portion of a larger map of the Sacramento Basin Subregion, and represents previous "state-of-the-art" regional mapping. It was prepared from reference materials dating back from 30 years ago to more recently. The map is vastly generalized and of questionable validity when compared with ground observations. It by no means equates with the high level of information content obtainable from high altitude CIR photography.

Feasibility Analysis of ERTS-1 Imagery

The following Multispectral Scanner System (MSS) single bands have been studied in terms of vegetation/terrain informational content: green, number 4 (0.5-0.6 μm), red, number 5 (0.6-0.7 μm), infrared, number 7 (0.8-1.1 μm) and the false-color composite MSS 4-5-7 NASA/GSFC

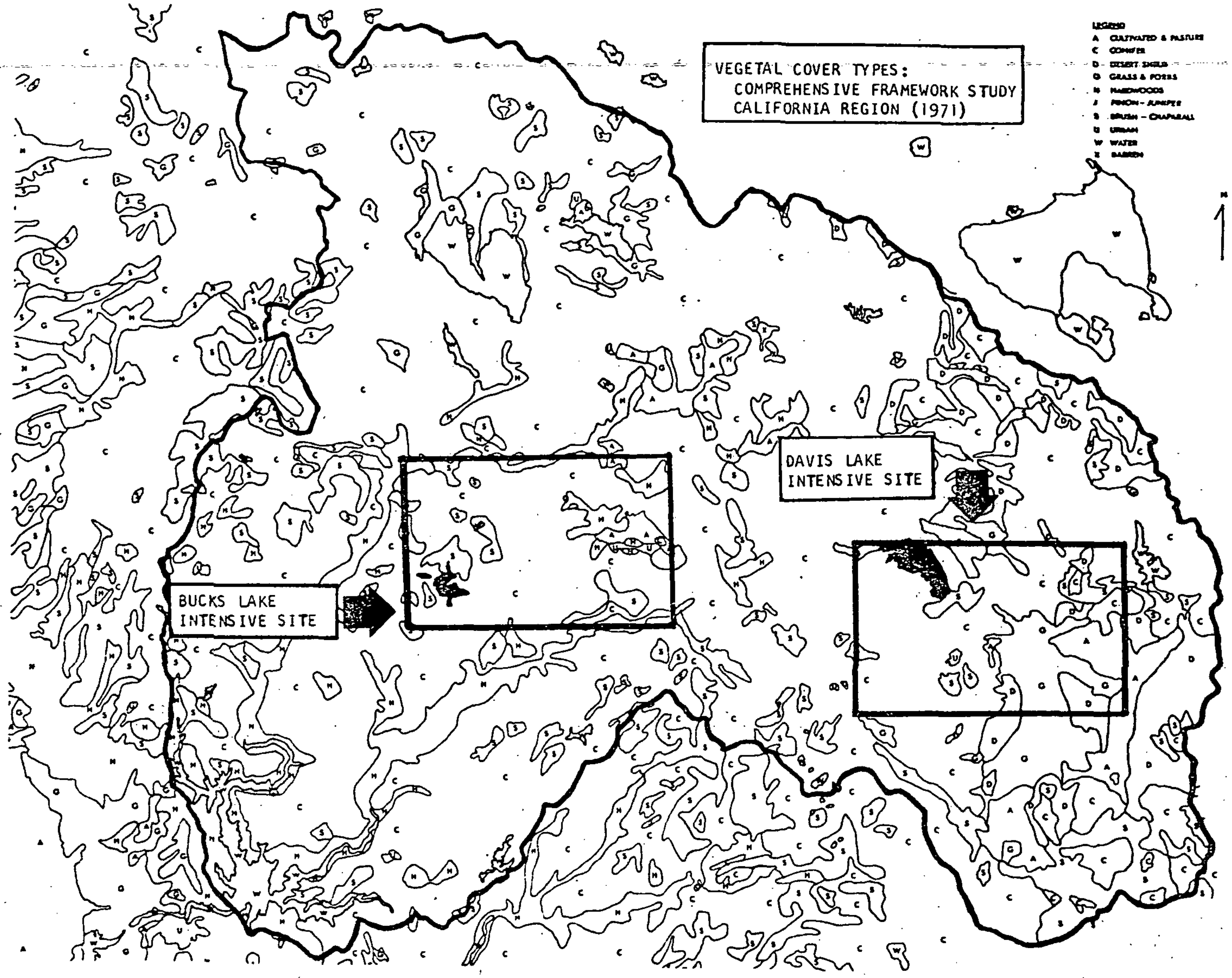


Figure 4.6. This modified version of the vegetal cover type map, prepared by the Comprehensive Framework Study, California Region represents previous "state-of-the-art" regional mapping. Within the Davis Lake intensive study area, the gross generality of resource information is apparent. Figure 4.5 illustrates current "state-of-the-art" resource mapping using high altitude false-color infrared imagery.

image. Original 1:1,000,000 single band, single date (July 25, 1970) black-and-white transparency images were professionally enlarged to a 16 x 20 inch print format, approximating the ground control map-scale of 1:250,000. The color combined MSS image used in this initial evaluation was a third generation copy enlargement (16 x 16 inch) derived from an available 9 x 9 color print of the region. Homogeneously appearing areas were delineated on overlays of these four enlarged images by two trained photo interpreters.

Evaluations of these delineations on each MSS single band and the color-combined image, were accomplished by direct visual comparison with analogous areas on the ground control maps. Image evaluation centered on the ability of the analyst to both detect and identify resources. These comparisons between and among images and ground-control maps, formulated the basis for preparation of a feasibility diagram (see Table 4.4) which initially assessed the interpretability of the ERTS-1 images. High altitude false-color infrared imagery was also evaluated.

The results shown in Table 4.4 generally indicate and equate interpreter ability to detect resources; however, object identification generally appears more difficult. The MSS green band number 4 appears useful in Eastside Valley and Basin Front Sagebrush-Scrub identification, and in the detection of main highways and logging roads. The MSS red band number 5 has been assessed as useful in identification of Fir forest, Intermediate Interior Valley Xeric grassland, Mesic Cultivated croplands, Mesic rangeland, Xeric Eastside grassland-Scrub rangeland,

TABLE 4.4. THE FEASIBILITY OF WILDLAND LANDSCAPE FEATURE DETECTION AND IDENTIFICATION WITHIN THE FEATHER RIVER WATERSHED REGION ON HIGH ALTITUDE AND ERTS-1 IMAGERY

LEGEND

- ● ● ● EASILY DETECTABLE
- ● ● MARGINALLY DETECTABLE
- ● NOT DETECTABLE

- ● ● ● EASILY IDENTIFIABLE
- ● ● MARGINALLY IDENTIFIABLE
- ● NOT IDENTIFIABLE

IMAGERY PARAMETERS										
VEHICLE	HIGH ALT. RB57		ERTS-1		ERTS-1		ERTS-1		ERTS-1	
SENSOR SYSTEM	RC-8 CAMERA		MSS BAND #4		MSS BAND #5		MSS BAND #7		MSS BANDS 457	
MISSION # & DATE [a]	MX 139(7-25-70)		(7-25-72)		(7-25-72)		(7-25-72)		(7-25-72) [b]	
ORIGINAL IMAGE TYPE	FALSE COLOR IR		B&W TRANS.		B&W TRANS.		B&W TRANS.		CIR ENHAN. TR.	
INTERPRETED IMAGE TYPE	CIR TRANS.		B&W PRINT		B&W PRINT		B&W PRINT		COLOR PRINT [c]	
ORIGINAL FORMAT	9 X 9 in.		9 X 9 in.		9 X 9 in.		9 X 9 in.		9 X 9 in.	
INTERPRETATION FORMAT	9 X 9 in.		16 X 20 in.		16 X 20 in.		16 X 20 in.		16 X 16 in.	
IMAGE SPECTRAL RANGE	0.4 - 0.9μm		0.5 - 0.6μm		0.6 - 0.7μm		0.8 - 1.1μm		.5-.7 & .8-1.1μm	
ORIGINAL IMAGE SCALE	1:120,000		1:1,000,000		1:1,000,000		1:1,000,000		1:1,000,000	
OBJECT RESOLUTION	20-30 FT.		200-300 FT.		200-300 FT.		200-300 FT.		200-300 FT.	
INTERPRETATION RESULTS	D*	I**	D*	I**	D*	I**	D*	I**	D*	I**
FOREST RESOURCES										
Coniferous Forests	●●●	●●●	●●	●●	●●	●●	●●	●	●●●	●●
A. High Elevation Red Fir Forest	●●●	●●●	●●	●	●●●	●●●	●	●	●●●	●●
B. Westside Intermediate Mountain Conifer	●●●	●●●	●●	●●	●●●	●●	●●	●	●●	●●
BB. Eastside Intermediate Mountain Mixed Conifer	●●	●●	●●	●	●●	●	●	●	●	●
C. Eastside Intermediate Pine-Scrub Forest	●●●	●●●	●●●	●●	●●●	●●	●	●	●●	●●
D. Eastside Northern Juniper Woodland	●●	●●	●	●	●	●	●	●	●	●
E. Eastside Timberland-Chaparral Complex	●●●	●●●	●●	●●	●●●	●●	●	●	●●●	●●
Hardwood Forests	●●●	●●●	●●	●	●●	●●	●	●	●●	●
F. Intermediate Mountain Xeric Hardwoods	●●●	●●●	●●	●	●●	●	●	●	●●	●●
G. Westside Foothill Pine-Oak Woodland	●●●	●●●								
GG. Westside Foothill Oak Woodland-Grass	●●●	●●●								
GC. Westside Foothill Oak Woodland-Chaparral	●●●	●●●								
GGC. Westside Foothill Oak Woodland-Grass-Chaparral	●●●	●●●								
H. Mixed Mesic Hardwood Communities	●●●	●●●	●	●	●	●	●	●	●	●
I. Westside Foothill Mixed Hardwood-Conifer Forest	●●●	●●●								
NON-FOREST RESOURCES										
Chaparral	●●●	●●●	●●	●●	●●	●●	●●	●	●●●	●●
J. Westside Valley Front Foothill Chaparral	●●●	●●●								
K. Westside Intermediate Mountain Chaparral	●●●	●●●	●●	●	●●●	●●	●●	●	●●●	●●
KK. Eastside Intermediate Mountain Chaparral	●●●	●●●	●●	●●	●●●	●●	●●	●	●●●	●●
L. Eastside Valley and Basin Front Sagebrush Scrub	●●●	●●●	●●●	●●●	●●●	●●	●	●	●●●	●●
Grassland-Meadow-Marshland Complex	●●●	●●●	●●	●	●●	●	●	●	●●●	●●
M. Subalpine Grassland										
N. Intermediate Interior Valley Xeric Grassland	●●●	●●●	●●●	●●	●●●	●●●	●	●	●●●	●●●
O. Mesic Meadow Complex	●●●	●●●	●●	●	●●	●●	●	●	●	●
P. Freshwater Marshland	●●●	●●●	●●●	●●	●●●	●●	●●	●	●●●	●●●
AGRICULTURAL AND RANGELAND RESOURCES										
Q. Mesic Cultivated Croplands	●●●	●●●	●●	●	●●●	●●●	●●●	●●●	●●●	●●●
R. Mesic Rangeland	●●●	●●●	●●	●●	●●	●●●	●	●	●●	●●●
S. Xeric Eastside Grassland-Scrub Rangeland	●●●	●●	●●●	●●	●●●	●●●	●	●	●●●	●●●
OTHER LANDSCAPE FEATURES										
T. Forest Plantation Sites	●●●	●●●	●●●	●●	●●●	●●	●	●	●●●	●●
U. Urban-Residential-Commercial Sites	●●●	●●●	●●	●	●●●	●	●	●	●●	●
V. Exposed Soil	●●●	●●●	●●	●●	●●	●●	●	●	●●	●●
W. Exposed Bedrock	●●●	●●	●●●	●●	●●	●●	●	●	●●	●●
WB. Basalt	●●●	●●●	●●	●	●●	●	●	●	●●●	●●●
WA. Andesite	●●●	●●	●●	●	●●●	●●	●	●	●●	●
WR. Rhyolite	●●	●●								
WP. Pyroclastics	●●●	●●	●●	●	●●	●	●	●	●●	●●
WG. Granite	●●●	●●●	●●	●	●●●	●●	●	●	●●	●●
WU. Ultrabasics	●●●	●●●	●●	●	●●●	●	●	●	●●●	●●
WS. Sedimentary	●●●	●●●	●●	●	●●●	●●●	●●	●	●●	●●●
WM. Metavolcanics	●●	●●	●	●	●	●	●	●	●	●
HYDROLOGIC RESOURCES										
X. Standing Water	●●●	●●●	●●	●●	●●●	●●●	●●●	●●●	●●●	●●●
Y. Running Water	●●●	●●●	●	●●	●●	●●	●	●	●●	●●
Z. Snowpack	●●●	●●●								
MISCELLANEOUS FEATURES										
ZA. Recent Fire Scar	●●●	●●●	●	●	●●	●	●●●	●●	●●●	●●
ZB. Main Highway	●●●	●●●	●●●	●●●	●●●	●●●	●	●	●●●	●●
ZC. Landslide Scar	●●●	●●●	●●	●	●●●	●	●	●	●●	●●
ZD. Logging Roads	●●●	●●●	●●	●●●	●●●	●●●	●	●	●●	●●

* DETECTION .... THE ABILITY TO DISCRIMINATE AN IMAGE ENTITY FROM THE SURROUNDING TONE MATRIX.

** IDENTIFICATION .... THE ABILITY TO CLASSIFY AND ASSIGN A NAME TO AN IMAGE DETERMINED BY ITS UNIQUE CHARACTERISTICS SUCH AS COLOR, TONE, TEXTURE, SHAPE, PATTERN, SIZE, ASSOCIATION OR OTHER QUALITY.

[a] Feasibility of image identification includes consideration of sequential imagery.
[b] MSS color-combined enhanced image transparency.
[c] The enlarged print used in this interpretation was fifth generation.

sedimentary bedrock, standing water and highways and logging roads. Perhaps the least useful single band image with respect to vegetation/ terrain type identification is the infrared band number 7, where only Mesic Cultivated croplands, and standing water are clearly identifiable. Furthermore, these results indicate interpreter ability to identify the following wildland resources on the MSS 4-5-7 false-color combined image: Intermediate Interior Valley Xeric grassland, Fresh water marshland, Mesic Cultivated croplands, Mesic rangeland, Xeric Eastside grassland-Scrub rangeland, Exposed Basalt bedrock, sedimentary rock, and standing water.

Development of Interpretation Aids

The approach used toward developing manual techniques for ERTS-1 imagery analysis has been initially confined to the Davis Lake intensive study area, although methods and procedures are applicable throughout the entire region. The method of enlarging the intensive study area, which is about 4 percent of the 9 x 9 ERTS-1 color composite image, involved the use of a Simmon Omega variable condenser with a Componon 1:5.6/135 Schneider Kreuznach lens. The single ERTS-1 image, July 26, 1972, was projected downward onto high quality white bond paper to a scale of 1:250,000.

One eighth inch diameter test cells (0.196 square miles on the ground) were established on a random basis within the homogeneous delineated areas (scale 1:250,000). The total sample population area (59 mi^2) represents about 9 percent of the Davis Lake intensive study area (630 mi^2). Distribution of the 300 test cells is seen in Figure 4.7.

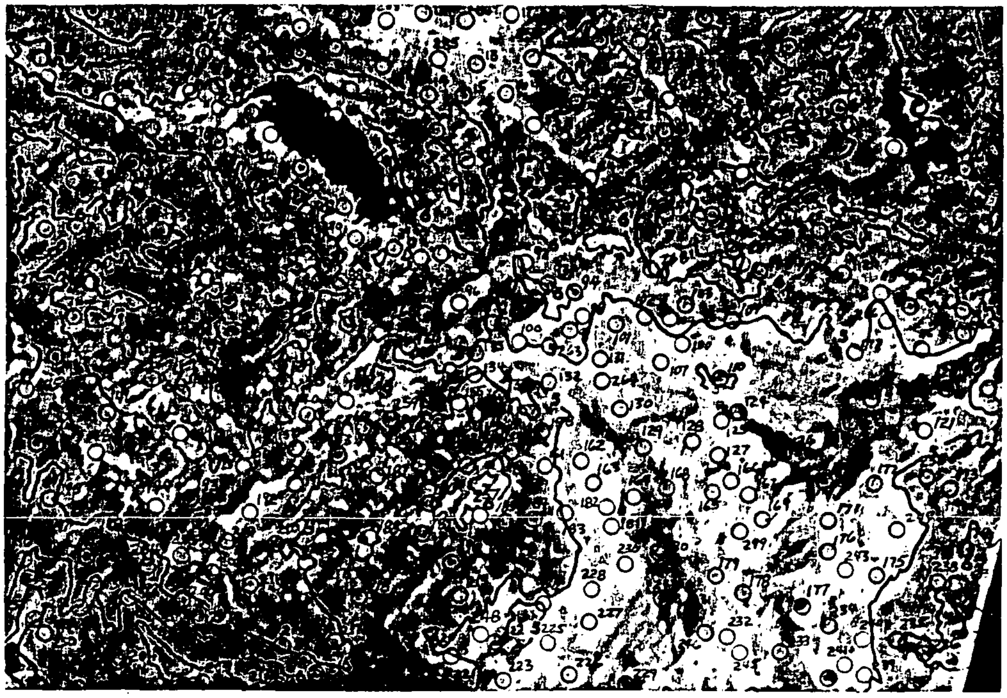


Figure 4.7. Mean annual precipitation overlay (top) and elevation zonation with 1000 foot contour interval overlay (bottom) on projected ERTS-1 image of the Davis Lake intensive study area. The numbered circles are 0.196 mi^2 test cells used in the quantitative interpretation test. Davis Lake (upper center) is five miles long (original image scale = 1/250,000).

This figure contains "overlays" of mean annual precipitation and elevation zonation, exemplary of interpretation aids.

The 1970 Munsell Book of Color was used to quantify the color attributes (hue, value, chroma) of each of the test cell circles, independent of resource delineation or classification. Interpolation of Munsell Color data was necessary in many instances since subtle color variation between the projected color within the test cell area and the Munsell Color chips often existed.

The resource classification of each test cell, with the associated Munsell color determination, provides the basis for the derivation of ERTS-1 image interpretation keys specific to the area and the image used. The technique used in establishing these keys to wildland resources is applicable, however, to any ERTS-1 image.

Another expression of the Munsell color data which quantifies the Davis Lake resources color attributes on the ERTS-1 image is presented in Figure 4.8. These diagrams are two dimensional renditions of a hue section (2.5PB-10YR) of the color solid. In Figure 4.8 color value (brightness) increases toward the bottom, thus the sequence adds 3-D to the illustration. It is apparent that several types (X,WB,V/S,V) are readily separate from the others, and thus are detectable and probably identifiable. Difficulty in separating many resources is also apparent, since a significant degree of color tone overlap occurs between and among them. Within the 3-5 value range, saturated reddish purple to red colored resources (BB,KK,E,A) overlap considerably. The chaparral (KK), however, could probably be distinguished from Fir forest

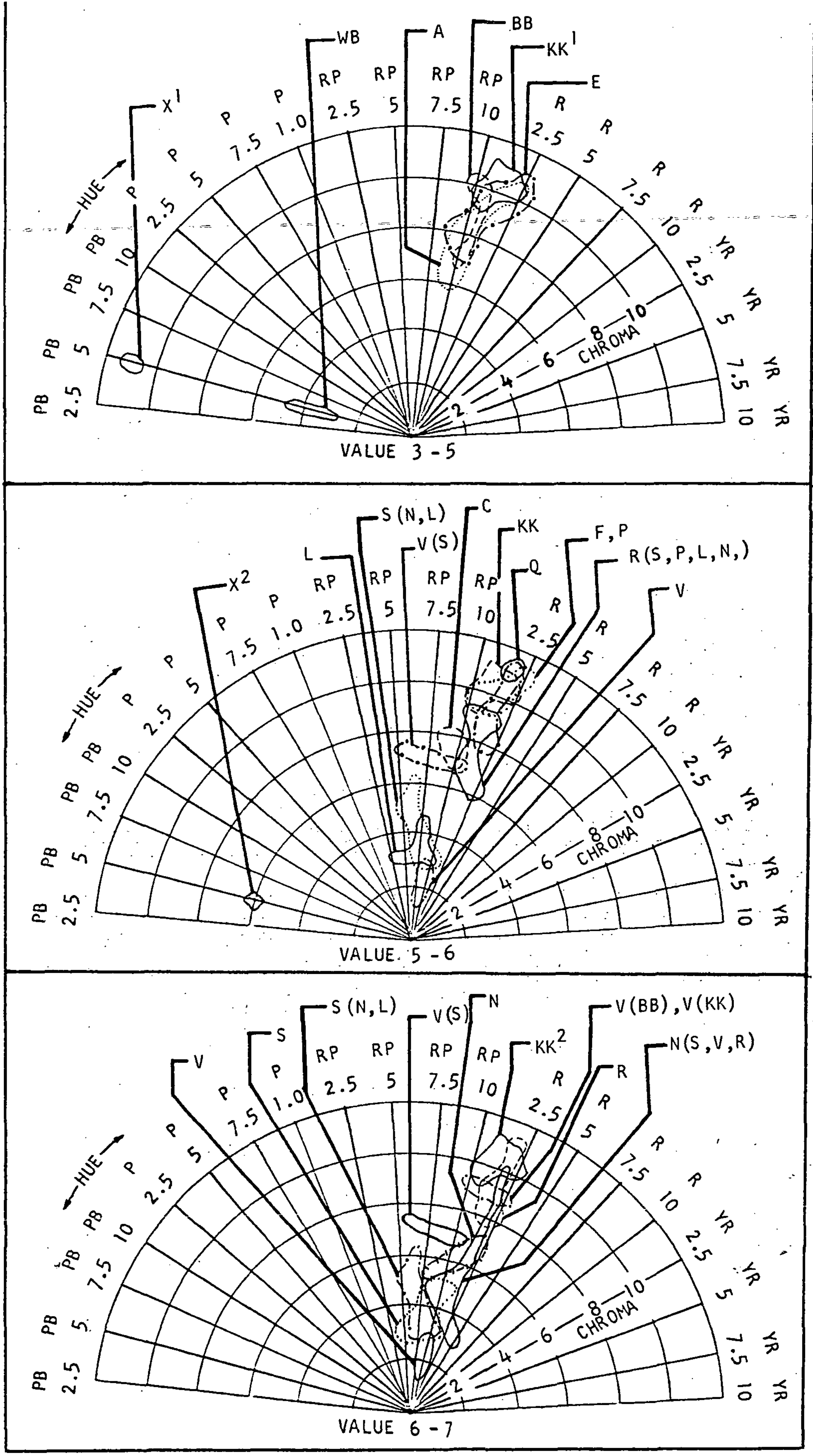


Figure 4.8. These Munsell color diagrams illustrate the relative degree of discrimination between and among wildland resource entities within the Davis Lake study area. (See text for explanation.)

(A) on the basis of subtle hue and saturation differences. It is apparent that resource types L, S(N,L),V,V(S)S separate easily from the other present, since the hue ranges are very low in saturation and are greyish-reddish-purple in color tone. The resource types KK,C,Q, F,P,R(S,P,L,N) generally overlap over the chroma range 6-11 in the red-purple to red hue range. However, even several of these types can be differentiated based on chroma separation and subtle hue variations. In the very light tone signature resources, value 6-7, many types are distinguished based on chroma separations and subtle hue variations. Consequently, these Munsell color diagrams in themselves represent useful interpretation guides to resource discriminations on ERTS-1 imagery, although they may be applicable only to this particular color composite image. For any other color composite image which may have been processed slightly differently than the one used in this test, the general degree of color discrimination between resource entities would be similar to what is shown in Figure 4.8, but the absolute color notations would be slightly different.

Munsell color ranges, corresponding ISCC-NBS color names, and precipitation and elevational data, provided the basis for constructing a dichotomous interpretation key specific to 18 resource categories. This key proved to be too complex for use in practical photo interpretation and required simplification for actual use.

The interpretation key (see Figure 4.9), used in the interpretation test discussed below, is a simplified version of the original key which contained Munsell color range notations. The modified key replaces these

2. Color dark blue; resource boundary distinct (see test cell No. 35) .... STANDING WATER (LAKE OR RESERVOIR) (X)

2. Color moderately dark blue; resource boundary not necessarily distinct.

3. Color is more saturated with blue, light blue, boundary distinct .... STANDING WATER, SHALLOW POND WITH HIGH SEDIMENT OR SALT CONTENT (X)

3. Color is less saturated; boundary indistinct; resource often mottled with light tones and red colorations .(No. 52) .... EXPOSED BASALT BEDROCK (WB)

1. Color is red, ranging from very pale or light gray-red, light pruplish gray-red or other pale color variants, to moderate strong, bright, saturated or dark red, orange-red or purplish red.

4. Colors are mostly moderately dark to strongly saturated or dark red (Nos. 4,55,84,82,144,294,252); some tones appear bright (Nos. 143,199, 273)

5. Red color tones are moderately dark (Nos. 79, 93,160), but color may be strong or saturated and red to red-orange (No. 188). The resource is often mottled with pale lighter tones (Nos. 93, 267) .... EASTSIDE INTERMEDIATE MOUNTAIN CHAPARRAL (KK)

5. Red color tones are mostly dark and colors range from a dark purplish-red (Nos. 49, 85) to dark strong red (Nos. 156, 206, 25, 28) and dark orange-red (Nos. 144, 31, 214)

6. Mean Annual Precipitation (MAP) predominantly ranges 30-50 inches; Color tone is dark purplish red to dark purplish brownish red (Nos. 4, 274). Resource occurs in smaller scattered areas.

7. Elevational range: 7000 - 8000 feet (+) .... FIR FOREST (RED FIR) (A)

7. Elevational range: 5000 - 7000 feet (±) .... FIR FOREST (WHITE FIR) (A)

6. MAP ranges from less than 40 inches.

8. MAP ranges 18 - 30 inches; color is moderate red, moderate purplish red (Nos. 95, 221), to light purplish red (Nos. 29, 115); Elevational range 5000 - 6000 feet .... EASTSIDE INTERMEDIATE PINE-SCRUB FOREST (C)

8. MAP ranges 18 - 35 inches; color is moderately dark, saturated, or strong.

9. Color is mostly strong orange-red, strongly red (No. 144) or purplish red (No. 217). Elevational range is 5000 - 7000 feet; Resource type is extensive .... EASTSIDE TIMBERLAND CHAPARRAL COMPLEX

9. Color is less orange-red, more strongly red to moderate purplish-red (Nos. 9, 80, 256); elevational range is 4000 - 7000 feet; this resource type is transitional .... EASTSIDE INTERMEDIATE MOUNTAIN MIXED CONIFER (BB)

4. Colors are moderately light (Nos. 171, 228) and bright (No. 122) to very bright (No. 118) and light (No. 243) in tone, except for dark pinkish gray areas. (Nos. 10, 131, 174).

10. Colors range from purplish red-gray (No. 174) to gray-pink (No. 192); Colors are low in saturation

11. Color tone relatively dark purplish red-gray (No. 174) to moderately dark pinkish gray (No. 171) (high to low density, respectively); saturation is low; elevational range 4000 - 6000 feet .... EASTSIDE VALLEY AND BASIN FRONT SAGEBRUSH-SCRUB (L) (L-6,Dense) (L-4,Sparse)

11. Color tone lighter; light or pale purplish gray (No. 127); Elevational range 4000 - 5000 feet .... XERIC EASTSIDE GRASSLAND SCRUB RANGELAND (S)

10. Colors range from light pink to pale orange-red.

12. Color tone is varied; color saturation may be strong, but generally is not.

13. Color tone is moderately light (No. 47) to very light (No.63); Resource associated wtih bright red to moderate orange-red mesic rangeland areas. This type is not extensively homogeneous within this region .... INTERMEDIATE INTERIOR VALLEY XERIC GRASSLAND (N)

13. Color tone is less than moderately light.(No. 47)

14. Color saturation is moderate (Nos. 38,218, 5, 94); Color tone is moderate but may be very light(No.182) where soil is completely void of vegetation cover .... EXPOSED SOIL OR ROCK WITH SPARSE GRASS OR CHAPARRAL COVER (V), (W), (V-KK)

14. Color saturation is moderately low; tones are moderate; color may be grayish (No.130) or pinkish gray(Nos.128, 192)..... MIXED GRASSLAND SCRUB RANGELAND. S(R,L,N)

12. Color tone is moderate to light; color saturation is usually strong to bright; color appears strong pink, red or red orange.

15. MAP ranges 10 - 40 inches.

16. Elevation ranges 4000 - 7000 feet; Map ranges 20 - 30 inches; resource mix varied, occurs as pale gray-red N(S) (No.33) or slightly brighter red N(R) (No. 65); resource type varied and not extensive .... MIXED XERIC GRASSLAND N(R), N(L), N(S)

16. Elevation ranges 4000 - 7000 feet

17. Elevation ranges 4000 - 5000 feet; pattern discernible as small squares or areas with right angle corners (No.176). MAP ranges 10 - 14 inches; color is bright to moderate red or red- orange (No.122) .... CULTIVATED CROPLANDS (Q)

17. Elevation varied; rightwangular pattern not discernible.

18. MAP ranges 10 - 14 inches; elevation ranges 4000 - 6000 feet; color is red-orange often occurring as strong bright red of pink areas within extensive dark red or purplish-red areas (No. 194); resource may appear elongate .... MESIC RANGELAND (R)

18. MAP ranges 14 - 35 inches.

19. Elevation ranges 5000 - 7000 feet; MAP 18 - 35 inches; very few extensive homogeneous areas of this resource occur within this region .... INTERMEDIATE MOUNTAIN XERIC HARDWOOS (F)

19. Elevation ranges 400 - 5000 feet; MAP ranges 12 - 16 inches; color mottled red to dark purplish red (No. 124, 170); resource often elongate occurring within gray areas; associated with bright strong red areas (No. 229)... MARSHLAND (P)

Figure 4. 9. An ERTS-1 image interpretation key to wildland resources within the Davis Lake study area of the Feather River Watershed region.

data with word descriptors of color ranges. Training cells were provided to guide the interpreters through the key.

An ERTS-1 Quantitative Image Interpretation Test

The purpose of this interpretation test experiment was to quantitatively assess the ability of two interpreters to utilize the ERTS-1 image interpretation key (see Figure 4.9) to identify and classify wildland resources within the Davis Lake intensive study area. The NASA Goddard ERTS-1 false-color composite (MSS 4-5-7) image was used in the test. It should be emphasized, however, that the vegetation/terrain entities are of an ecologically diverse nature and often confound interpretation by occurring in varying proportions within homogeneously appearing areas.

The test was given to two skilled interpreters. Interpreter A was familiar with the Davis Lake study area resources, but Interpreter B generally was not. The ERTS-1 image was projected on to the 300 test cells indicated in Figure 4.7. Acetate overlays of precipitation and elevational zonation aided the decision making process. Sixty-seven specific known resource training cells were indicated on the answer sheet provided, such that the interpreter could study the variations in tone signatures. Each interpreter was asked to identify approximately 200 test cell areas with respect to (1) specific dominant vegetation/terrain resource type, and (2) general resource type. The identity of each training and test cell has been verified with the aid of the ground controlled data (see Figure 4.5).

Results of the interpretation test given to Interpreters A and B are presented in Tables 4.5 and 4.6. The "number indicated" refers to

TABLE 4.5. RESULTS OF THE INTERPRETATION TEST OF SPECIFIC VEGETATION/ TERRAIN TYPES USING AN ERTS-1 COLOR COMPOSITE TRANSPARENCY.

SPECIFIC RESOURCE TYPE	NO. TEST CELLS	INTERPRETER IDENTIFICATION	NO. INDICATED	NO. OMITTED	NO. CORRECT	NO. COMMISSION ERROR	PERCENT OMISSION	PERCENT COMMISSION (I) [c]	PERCENT COMMISSION (II) [d]	PERCENT CORRECT
A	10	A[a]	7	3	7	0	30	0	0	70
		B[b]	9	4	6	3	40	30	33	60
BB	10	A	4	8	2	2	80	20	50	50
		B	2	9	1	1	90	10	50	10
C	9	A	13	4	5	8	44	88	61	55
		B	11	4	5	6	44	66	54	55
E	35	A	38	5	30	8	14	22	21	85
		B	53	5	30	23	14	65	43	85
F	3	A	1	3	0	1	100	33	100	0
		B	0	3	0	0	100	0	0	0
KK	29	A	32	6	23	9	20	31	28	79
		B	24	10	19	5	34	17	20	65
L	24	A	30	2	22	8	8	33	26	91
		B	19	12	12	7	50	29	36	50
N	9	A	0	9	0	0	100	0	0	0
		B	7	5	4	3	55	33	42	44
P	3	A	1	2	1	0	66	0	0	33
		B	1	2	1	0	66	0	0	33
Q	5	A	3	2	3	0	40	0	0	60
		B	3	2	3	0	40	0	0	60
R	21	A	23	3	18	5	14	23	21	85
		B	19	5	16	3	23	14	15	76
S	16	A	14	6	10	4	37	25	28	62
		B	23	0	16	7	0	43	30	100
V	6	A	5	5	1	4	83	66	80	16
		B	5	4	2	3	66	50	60	33
W	8	A	2	7	1	1	87	12	50	12
		B	0	8	0	0	0	0	0	0
WB	4	A	4	0	4	0	0	0	0	100
		B	3	2	2	1	50	25	23	50
X	6	A	6	0	6	0	0	0	0	100
		B	6	0	6	0	0	0	0	100
TOTAL	198	A	183	55	133	50	32	25	27	67
		B	185	75	123	62	37	31	33	62

[a] Results for Interpreter A

[b] Results for Interpreter B

[c] Error based on number of type present

[d] Error based on number of a type indicated

TABLE 4.6. RESULTS OF THE INTERPRETATION TEST OF BROAD VEGETATION/TERRAIN TYPES USING AN ERTS-1 COLOR COMPOSITE TRANSPARENCY.

COMPONENTS	A,BB,C,E		F,H		KK,K		N,N(V)		Q		R,P		L,S		V,W,WB		X			
COMPREHENSIVE RESOURCE	CONIFEROUS FOREST		HARDWOOD FOREST		MOUNTAIN CHAPARRAL		XERIC GRASSLAND		CULTIVATED CROPS		MESIC RANGELAND		SAGEBRUSH SCRUB		EXPOSED SOIL		STANDING WATER		TOTALS	
NO. TEST CELLS	71		4		31		17		4		23		44		10		6		210	
INTERPRETER ID	A[a]	B[b]	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
NO. CORRECT	57	60	0	0	23	19	0	4	4	3	22	17	36	32	7	4	6	6	155	145
NO. COMMISSION	6	15	1	0	9	5	0	3	0	0	4	4	7	8	5	3	0	0	32	38
NO. INDICATED	63	75	1	0	32	24	0	7	4	3	26	21	43	40	12	7	6	6	187	183
NO. OMITTED	14	11	4	4	8	12	17	13	0	1	1	6	8	12	3	6	0	0	55	65
PERCENT OMITTED	19	15	100	100	25	38	100	76	0	25	4	26	18	27	30	60	0	0	26	30
PERCENT COMMITTED[c]	8	21	25	0	29	16	0	17	0	0	17	23	15	18	50	30	0	0	15	18
PERCENT COMMITTED[d]	9	20	100	0	28	20	0	42	0	0	15	19	16	20	41	42	0	0	17	20
PERCENT CORRECT	80	84	0	0	74	61	0	23	100	75	95	73	81	72	70	40	100	100	73	69

[a] Results for Interpreter A

[b] Results for Interpreter B

[c] Error based on number of type present

[d] Error based on number of a type indicated

the number of test cells which the interpreter indicated were of a certain resource type. The "number omitted" refers to the number of cells of a certain resource type that the interpreter omitted. Commission error contrasts with omission error in that it refers to the accumulation of incorrect interpretations (e.g., when type "A" is incorrectly called type "B", two errors have been made -- "A" has been omitted and "B" committed). The number of test cells known to be of a certain resource type from ground control information is also indicated in these tables.

The results of this photo interpretation test are expressed as percent correct, percent omission, and percent commission error. Commission error is expressed as the number of errors of a type based on (1) the total number of the resource type present in the test or (2) the number of errors of a type based on the total number of that type indicated.

The results of specific resource type identification on the ERTS-1 image are presented in Table 4.5. Overall they indicate that both interpreters were about 65 percent proficient in interpreting all resources on the image. Both interpreters correctly identified all standing water bodies (X), and showed generally high proficiency (>60 percent) in correctly identifying Fir forest (A), Eastside timberland-chaparral forest (E), Mountain chaparral (KK), Eastside Valley and Basin Front Sagebrush-Scrub (L), Cultivated croplands (Q), Mesic rangeland (R), Xeric Eastside grassland-scrub rangeland (S), and Exposed Basalt. Among these resource types, commission errors were generally low (<35 percent) except for high commission error for the timberland-chaparral type (E) by Interpreter B.

Omission errors were also generally low (see Table 4.5) indicating

interpreter ability to detect these resources where they occur as varying tone signatures. A high (50 percent) omission error occurred for Exposed Basalt by Interpreter B since he was biased toward identifying surrounding timber types (correctly) as opposed to the test cell type (WB). This result no doubt reduces the overall percent correct otherwise obtainable.

Marginal interpreter proficiency was demonstrated for resource types BB, C, N, P, V, and W, while neither interpreter correctly detected nor identified the few hardwood types presented. Combined interpreter results compared well with the feasibility indicators (presented in Table 4.4) except for resource types L, KK, E, and A which were more easily identifiable than expected.

It is apparent that Interpreter A detected no Xeric grassland (N) types and Interpreter B detected no exposed rock (W) types although both types were present. In most cases, difficulty was encountered in distinguishing among V, W, N resource types; A, BB, E resource types; and C, KK, R resource types. These results were apparent in the test correction process. From these results (Table 4.5), it is apparent that the most difficult types to detect were BB, F, P, V, C, and W, and proficiency in correctly identifying these resources was low.

Results presented in Table 4.6 indicate high interpreter proficiency in interpreting broad resource types including coniferous forests, cultivated croplands, standing water bodies, sagebrush types, mesic rangeland-marshland, and mountain chaparral. Exposed soil and bedrock proved marginally identifiable by Interpreter B but more easily identifiable by Interpreter A. Both xeric grassland areas and hardwood forests were virtually undetectable resource entities and, therefore,

were not identified correctly. Among the broad resource types present in the Davis Lake study area, both interpreters were about <u>70 percent correct</u> overall in their interpretations. However, with increased training these results probably could have been improved.

<u>Determination of Time -- Cost Factors</u>

Table 4.7 shows projected interpretation time and costs associated with the task of producing vegetation/terrain resource maps from both high altitude and ERTS-1 imagery. Approximately sixty high altitude images, compared with one ERTS-1 image, are needed to compile a complete regional map. The total time required for imagery interpretation, including resource type classification, has been estimated to be seven times greater on high altitude than on ERTS-1 imagery. This coincides with a projected cost ratio on a per/acre basis, of 7:1, respectively. Of importance to these projected time and cost data, however, is the significant difference in resource information content between the aircraft and satellite images. The amount of resource information lost on the ERTS-1 image, however, remains to be assessed.

<u>Conclusions</u>

In this study on vegetation/terrain mapping, a procedure and technique for the development of ERTS-1 interpretation guides and keys has been demonstrated. The Munsell Color System, used to quantify color data and transformed into guides and keys, can prove useful in interpreting ERTS-1 images. Likewise, both precipitation and elevational data proved useful in aiding resource identifications in the Davis Lake study area.

The interpretation test results presented above indicate the

TABLE 4.7. PROJECTED INTERPRETATION TIME AND COSTS OF REGIONAL FEATHER RIVER WATERSHED IMAGE ANALYSIS

TASK	HIGH ALTITUDE CIR TRANSPARENCY (9 x 9 in.)	ERTS-1 COLOR ENHANCED FALSE-COLOR ENLARGED PRINT (16 x 16 in.)
DELINEATION OF WATERSHED BOUNDARY (2.5 MILLION ACRES)	3.0 HOURS	0.5 HOURS
PLOTTING EFFECTIVE AREAS	5.0 HOURS	0.0 HOURS
DELINEATION OF HOMOGENEOUS AREAS	48.0 HOURS	3.0 HOURS
PHOTO INTERPRETATION TRAINING & TESTING	6.0 HOURS	2.0 HOURS
RESOURCE TYPE CLASSIFICATION	210.0 HOURS	30.5 HOURS
TOTAL INTERPRETATION TIME REQUIRED	272.0 HOURS	35.5 HOURS
HOURLY WAGE	\$7.00/HOUR	\$7.00/HOUR
TOTAL INTERPRETATION COSTS (TIME)	\$1,904.00	\$248.50
TOTAL COST/ACRE	0.07¢	0.0098¢
COST RATIO	7	1

relatively high interpretability of major resources within the Davis Lake study area of the Feather River Watershed region. High proficiency in resource identification was demonstrated by both interpreters for nine specific resource types. As expected, due to heterogeneity among types, certain types were difficult to separate and identify and often were confounded in the process of interpretation. However, those resource types deemed uninterpretable in the above test might yet prove interpretable if (1) the key were more explicit, (2) multidate imagery were used, (3) enhancements were devised to increase the proficiency of interpretation, and (4) interpreter training and experience increased.

It is apparent from these initial evaluations that ERTS-1 imagery interpretation is relatively rapid and less costly, in terms of time, than similar analysis performed on high altitude aircraft imagery. The level of information loss between these "stages" of imagery remains to be assessed. Without doubt, the high altitude CIR imagery provides a means for accurate regional resource analysis and mapping, a capability previously unrealized. Synoptic ERTS-1 imagery provides the means for continuous regional resources evaluation while high altitude imagery provides for immediate detailed area analysis.

4.2.1.3 Snow Surveys

With respect to snow surveys in the Feather River region, section 228 of the California Water Code states that the Department of Water Resources will gather snow data, through the California Cooperative Snow Survey Program, in order to forecast seasonal water supplies. Many county, state and federal agencies and private organizations

participate in this program and obtain snow data by standard snow survey methods on established courses. However, for the entire 2.5 million acre Feather River Watershed region, snow data are collected at only 25 point locations from which water inflow forecasts are made for the Oroville Reservoir facility. Consequently, the long range goal of the snow survey work being conducted by the FRSL is to provide improved means for estimating annual extent of snow cover during critical periods of the melt season. These data, if proven to be valid, could be used to improve the effectiveness of existing stream flow forecasting models.

Snow Study Objectives

The research objectives for the snow study during this reporting period were twofold. First, sequential U-2 high flight photography and field data were used to develop a suitable reference document, in the form of an image interpretation key, which could effectively be used by a trained image analyst when interpreting areal extent of snow in forested areas. Second, an efficient manual analysis technique was developed for estimating acreages of snow. This technique capitalizes on the human's ability to amalgamate information on (1) the appearance of snow as seen on high flight photos and (2) the type, density and distribution of the vegetation/terrain within which the snow occurs and which greatly influences the appearance of snow.

Methods and Procedures

In the past, the major difficulty in studying snow cover over vast areas within the Feather River Watershed was the lack of suitable synoptic view imagery. During the 1970-71 melt season, small scale (1:100,000)

70 mm black-and-white photographs were procured (by a private contractor) on five different occasions. Only the Spanish Creek Watershed was flown, and more than 80 photographs were required to cover this area. During the 1971-72 season, the NASA U-2 aircraft stationed at the Ames Research Center flew four missions, each of which covered the entire Feather River Watershed. In addition, a U-2 aircraft flew a solo flight line centering over the Spanish Creek Watershed on May 21, 1969. Consequently, during this last reporting period, a sufficient amount of imagery was available for study.

In support of the recent U-2 missions, two methods were employed for collecting field data on true snow conditions -- field sampling and low altitude oblique aerial photography. On three dates in 1972, January 31, March 6 and March 28, a field crew visited a series of permanent plots established within the Spanish Creek Watershed. (these plots were described and illustrated in last year's annual progress report.) The field crews traveled by snowmobile and on snowshoes to each plot location. Snow depth and condition data were collected and recorded, consistent with California Cooperative Snow Survey procedures using Mount Rose snow sampling tubes.

Data collection on the ground, however, was very tedious and time consuming. Furthermore, only a few samples could be collected before so much time had elapsed that further sampling became meaningless with respect to a specific high flight mission. Consequently, the primary mode of ground data collection was with low altitude aerial oblique photography. By maintaining a flying altitude between 500 and 1,000

feet above ground and employing a 35 mm camera, with wide angle lens, color oblique photographs were taken which provided enough detail to ascertain the presence or absence of snow and which were snyoptic enough to provide good snow boundary information. Each permanent ground plot site, as well as many other targets of opportunity, were photographed in 1972 on January 10, January 31, March 28 and May 3.

Development of an Image Interpretation Key

A comprehensive image interpretation training and reference document was prepared which was designed to aid the trained image analyst while evaluating snowpack conditions as seen on synoptic view imagery. The primary value of this key is that it documents, in the form of word descriptions and photo illustrations, the appearance of snow when influenced by a variety of vegetation/terrain conditions. Thus, a selective type of key was prepared based on eight vegetation/terrain categories -- dense conifer forest, sparse conifer forest, dry site hardwood forest, brushland, meadow or rangeland, urban land, water or ice, and rock or bare ground. Within each category, examples were chosen under different conditions of elevation, steepness of slope and direction of slope (aspect). For example, within dense conifer forests snowpack conditions are described for (1) high elevation and steep north slopes, (2) high elevation and moderate north slopes, (3) high elevation and gentle south slopes, (4) medium elevation and flat areas, and (5) low elevation and steep north slopes. Each one of these specific examples represents an entire page in the key and consists of five illustrations -- one before the snow season, two at the height of snow accumulation and two during the depletion period

(see Figure 4.10). In the completed version of the key the eight vegetation/terrain type categories are illustrated with a total of twenty-two specific examples, each similar to the one shown in Figure 4.10.

Possibly the most important value of the image interpretation key is that it allows the image analyst to become cognizant of the fact that for any given area, snow may be present on the ground but may not be visible on the U-2 imagery. This situation often occurs within a dense coniferous forest in which a deep snowpack can be completely obscured by the crown canopy. It has been emphasized in the key, however, that the presence of snow in a dense forest usually can be deduced merely by examining the appearance of adjacent vegetation/terrain types. For example, if a dense stand of timber is surrounded by meadows or brushlands and snow can be detected within these adjacent types, the interpreter can safely predict that the dense, heavily shaded timbered area also contains snow.

Development of an Image Interpretation Technique

Previous research results (see last year's annual progress report dated May 1972) clearly have shown that four environmental factors greatly influence the appearance of a snow boundary, viz., elevation, slope, aspect and vegetation/terrain type. For example, in certain areas a snow boundary appeared to follow a line of equal elevation but dropped down in elevation considerably on north facing slopes. In addition, it was found that the presence or absence of snow and consequently the snow boundary was (1) easily detectable in meadows and bare areas, (2) sometimes, but not always, detectable in sparse coniferous forest and

SNOW CONDITIONS WITHIN SPARSE CONIFER FOREST

Density - 0-35% crown closure
Elevation - 5,500 feet
Terrain - gently sloping (0-10°) towards the south

September 21. No snowpack present. Photograph appears medium grey with a pebbly appearance. Roads easily distinguishable due to the lack of canopy interference and appear as white lines.

December 20. Three to four feet of snowpack present. Ground is continuously covered leaving tree crowns and their respective shadows as the only dark areas. The result is a predominant white with a speckling of dark areas. On this photograph, in the upper left hand corner of the indicated area, a dark grey area can be seen with scattered white spots. This is a slightly north facing slope and, due to the sun angle, the shadows have lengthened and now predominate the image appearance. However, snow conditions are the same as in the rest of the sparse conifer forest.

January 31. Over 6 feet of continuous snow cover is present. Sun angle has increased and shadowing has lessened. High reflectivity of the snowpack dominates the scene and the image is predominantly white with a scattering of dark spots.

March 6. Conditions essentially the same as on January 31, except sun angle is even higher, and due to photographic exposure problems, the small dark spots attributable to the trees and shadows are almost lost.

March 28. Snowpack has begun to deplete and is less than 6 feet deep. Due to the low percentage of canopy interference, the position of the snowpack is fairly evident. The areas of lower elevations are reverting to the medium-to-dark grey tone with the very pebbly texture, indicative of the absence of snowpack.

Figure 4.10. Illustrated here is an example page from the image interpretation key which shows snow conditions for a sparse coniferous forest type at high elevation on a gentle south facing slope. The completed version of the key illustrates 22 specific examples, each similar to the one shown here, found throughout the Spanish Creek watershed. The scale of the original U-2 photography used to make the key was 1/440,000 with a ground resolution of approximately 30 feet.

(3) nearly impossible to detect in dense coniferous forest. Once an image analyst is properly trained (with an interpretation key) to recognize various combinations of environmental conditions, and is aware of the relationships among these various conditions and the appearance of snow associated with them, he can effectively map snow boundaries on small scale imagery. However, acreage estimates of snow cover, not maps, are needed for making stream flow predictions. Consequently, a new approach to interpretation, using systematic sampling, is being tested which (1) allows a trained analyst to accurately estimate areal extent of snow, (2) can be applied to vast complex forested regions and (3) is fast and inexpensive to implement.

This new technique capitalizes on the ability of the human interpreter to amalgamate several kinds of information and to quickly arrive at a decision. In addition, a new piece of interpretation equipment is employed -- the Bausch and Lomb Zoom Transfer Scope. The interpretation procedure is as follows:

1. Using the Zoom Transfer Scope, observe two forms of data simultaneously -- e.g., a high flight photo and a topographic map annotated with vegetation/terrain information.

2. Place the images of these two forms of data as seen in the Transfer Scope in good register.

3. Adjust the lighting for each image such that each will fade in and out by adjusting the equipment controls.

4. Place a grid overlay on the topographic map. Note that a certain number of grid intersections fall within each watershed being analyzed

and, by adjustment of the lighting on the Transfer Scope, the annotated map with grid can be made to fade in and out of view.

5. For each circular plot (e.g., five acres) within which a grid intersection falls, the interpreter must decide if snow is present. For most plots, the decision is easy, snow obviously is or is not present. However, along the edge of the snowpack boundary the decision is difficult, and the interpreter must concentrate on two things -- appearance of snow and vegetation/terrain condition -- by adjusting the lighting in the Transfer Scope.

6. Classify each circular plot using the following scheme:

Code	Condition
1	No snow present
2	0-20 percent of ground covered by snow
3	20-50 percent of ground covered by snow
4	50-100 percent of ground covered by snow
5	100 percent of ground covered by snow

7. Examine each circular plot in the watershed and record interpretation results on a data sheet using the code given above.

8. Calculate the proportionate number of circular plots for each snow condition.

9. Calculate the total acreage for each snow condition class by applying these proportional values to the total area of the watershed.

10. Adjust downward the acreage estimate for each of the condition classes relating to boundaries (i.e., codes 2, 3, and 4) by multiplying the gross acreage values by the appropriate value of percent of ground

covered by snow (i.e., midpoint of percent cover class).

11. Sum the adjusted acreage estimates for the entire watershed.

Test Results and Conclusions

The interpretation technique described above and the image interpretation key were applied to the 4,600 acre Mill Creek Watershed located in the very center of the Feather River region. A group of ten interpreters studied the interpretation key and then, while working independently, estimated the areal extent of snow for the Mill Creek Watershed using 70 mm U-2 photography taken on March 28, 1972. Figure 4.11 illustrates the U-2 photography (top) and the annotated topographic map with grid overlay (bottom) which were employed during this experiment. An example data sheet compiled by one of the interpreters is shown in Figure 4.12. Note that for the Mill Creek Watershed, 115 sample points, each approximately 5 acres in size, were interpreted in terms of percent snow cover. The subsequent calculations resulting in a estimate of snow cover are given at the bottom of Figure 4.12. A summary table showing the range of estimates of percent snow cover for all 115 points is presented in Table 4.8.

As indicated in Table 4.8, which shows the range in interpretation estimates by ten interpreters, the interpreters were unable to agree on the snow cover classification for many of the points. A Chi-Square analysis of these data indicated that the individual interpreter's classification distributions were independent of each other, indicating a wide variety of classifications for many of the pointson the image. For each point where complete agreement by all ten interpreters occurred, the point

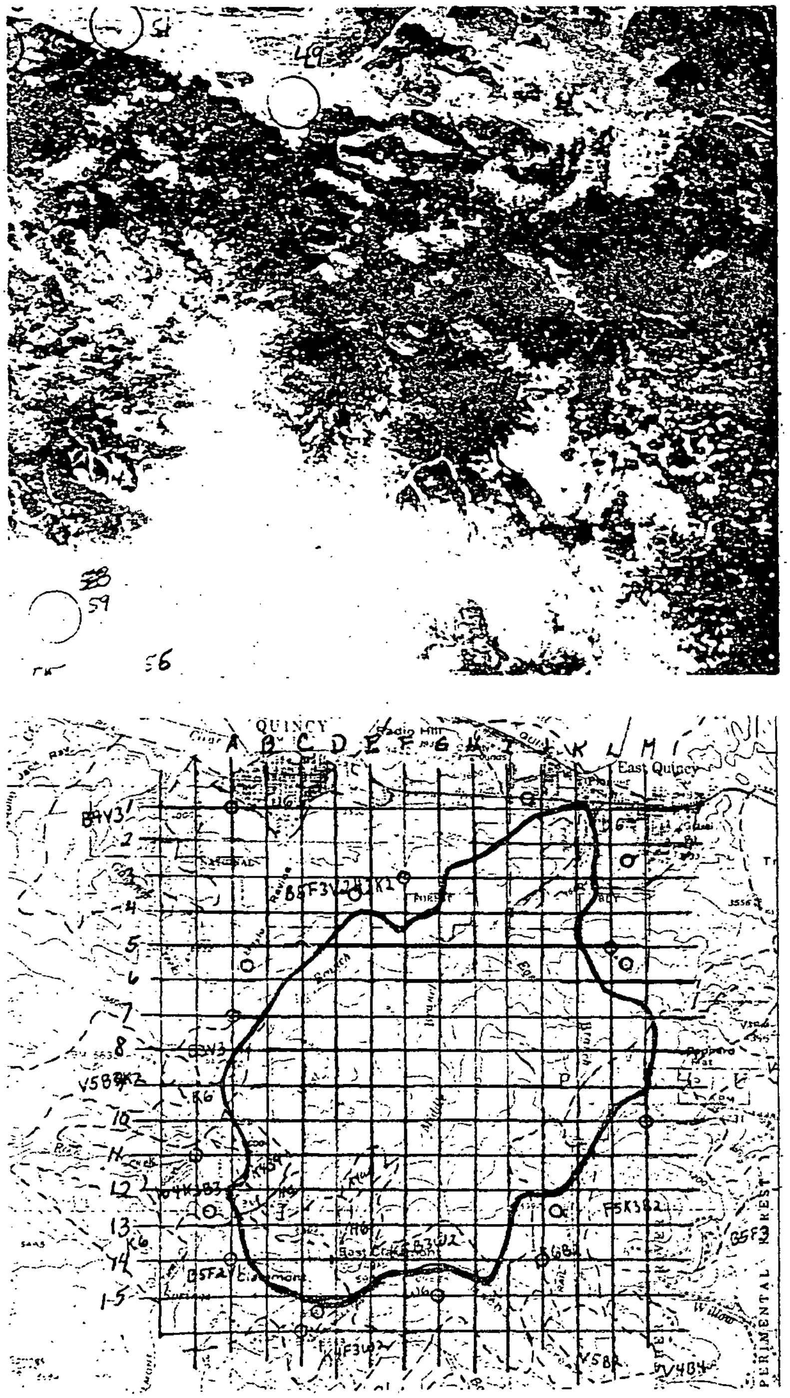


Figure 4.11. The enlarged U-2 photograph (top), taken on March 28, 1972, shows the 4600 acre Mill Creek watershed near Qunicy, California. By employing the topographic map (bottom) annotated with major vegetation/terrain information and correctly positioned in a Zoom Transfer Scope, ten interpreters estimated percent snow cover at each of the 115 grid intersections.

Watershed Mill Creek   Imagery U-2

Interpreter DTC   March March 28, 1972

	GRID POINTS													SUMMARY				
	A	B	C	D	E	F	G	H	I	J	K	L	M	1	2	3	4	5
1											1			1				
2									1	1	1			3				
3								1	1	1	1			4				
4					1		1	1	1	1	1			6				
5				1	1	1	1	1	1	1	1			8				
6			1	1	1	1	1	1	1	1	1			9				
7		5	2	1	1	1	1	1	1	1	1	1	3	9	1	1		1
8		5	2	1	3	1	1	1	4	1	2	4	4	5	2	1	3	1
9	5	4	2	2	4	3	1	1	2	4	3	5	5	2	3	2	3	3
10		5	5	5	5	2	1	1	3	5	3			2	1	2		5
11		5	5	5	5	2	2	5	5	5	5				2			8
12	5	5	5	5	5	5	5	5	5	5	5							10
13		5	5	5	5	5	5	5	5	5								8
14		5	5	5	5	5	5	5	5									7
15			5	5														2
														49	9	6	6	45

Snow condition #1 - 49/115 x 4600 = 1960
Snow condition #2 - 9/115 x 4600 = 360 x 10% = 36
Snow condition #3 - 6/115 x 4600 = 240 x 35% = 84
Snow condition #4 - 6/115 x 4600 = 240 x 75% = 180
Snow condition #5 - 45/115 x 4600 = 1800 x 100% = 1800

Total snow = 2100 acres

Figure 4.12. Interpretation results derived by each interpreter for the Mill Creek watershed were recorded on data sheets like the one shown here. The ordinate and abscissa grid coordinates shown on the topographic map in Figure 4.11 are given above as numbers 1 through 15 and letters A through M, respectively. Note that an estimate of percent snow cover was made for each of the 115 grid points (i.e., 1 = no snow, 2 = 0-20 percent snow, 3 = 20-50 percent snow, 4 = 50-100 percent snow and 5 = 100 percent snow). The calculations predicting total snow cover for the watershed are given at the bottom.

TABLE 4.8. RANGE OF INTERPRETATION ESTIMATES OF PERCENT SNOW COVER FOR 115 SAMPLE POINTS (TEN INTERPRETERS). MILL CREEK WATERSHED, MARCH 28, 1972

	A	B	C	D	E	F	G	H	I	J	K	L	M
1											0-10		
2									0	0	0-10		
3								0	0	0	0-10		
4						0	0-10	0	0	0	0		
5				0	0	0	0	0	0-10	0-10	0		
6			0-10	0	0	0	0	0	0-10	0-10	0-10		
7		0-100	0-35	0-75	0-75	0-10	0-10	0-10	0-75	0-75	0-10	0-75	0-75
8		10-100	0-75	0-75	10-100	0-35	0-35	0-10	0-75	0-75	0-75	10-100	0-100
9	75-100	35-100	10-100	0-100	10-100	10-100	0-35	0-75	10-100	0-100	10-100	10-100	75-100
10		75-100	75-100	75-100	10-100	0-100	0-75	0-75	10-100	75-100	10-100		
11		75-100	75-100	75-100	35-100	0-100	0-100	35-100	75-100	75-100	35-100		
12	100	100	100	75-100	75-100	35-100	35-100	75-100	35-100	100			
13		100	100	100	100	100	100	100	100				
14		100	100	100	100	100	100	100					
15		100	100										

Note: The ordinate and abscissa gird coordinates shown on the topographic map in Figure 4.13 are given above as numbers 1 through 15 and letters A through M, respectively.

classification was either 0 percent or 100 percent snow cover. Thus, as was predicted, the areas exhibiting show boundary conditions were the most difficult to interpret, and in this case the snowpack boundary passed through the middle of the watershed.

Some of the variation in the classifications is due, of course, to the variation in interpreter skill and knowledge about snow conditions. In one case, one of the most inexperienced interpreters made an obvious error by classifying points 1K and 2K as 10 percent snow cover, because that person confused the light toned urban area with areas of low density snow cover. However, at most of those points where the interpreters disagreed on the amount of snow present, one or more of the following three situations prevailed:

1. In areas of low density vegetation cover, the interpreter would classify exposed soil as patchy snow or vice versa (e.g., points 7D, 7E, and 7L).

2. The quantity of snow present in boundary areas betweeen vegetation types was difficult to determine on the imagery because snow conditions in the surrounding areas were not always indicative of the condition at the point in question (7B, 9J).

3. Photo interpreters had difficulty in determining how far down stream channels the snow line extended (10G).

All of the interpreters felt, however, that given more training and experience with this kind of an interpretation problem, they would be more confident and more accurate in predicting snow cover along the boundary area. In addition, each interpreter agreed that the technique

involving the use of the Zoom Transfer Scope greatly facilitated the interpretation task. Thus, it is anticipated that the newly developed interpretation technique applied to the Mill Creek Watershed could be employed with ERTS-1 imagery for the entire Feather River Watershed when estimating areal extent of snow cover.

4.2.2 Analysis Within the Northern Coastal Zone

4.2.2.1 Introduction

Within recent years, California's coastal land has come under mounting pressure by (1) developers who want to convert portions of the relatively undeveloped coast line into home sites for prospective buyers, (2) recreationists, who want to experience the beauty of the coastal region and gain access to the shoreline without hinderance from private land owners, (3) resource users who are converting the abundant vegetative and water resources into products for human consumption, and (4) utility companies, who seek sites for power generating facilities. Because the expected intensification of resource use in the north coast region could lead to serious environmental problems, the people of California enacted the Coastal Zone Conservation Act in November, 1972. This act created a California Coastal Zone Commission which will use 5 million dollars state and 15 million dollars federal money to generate a land use plan (California Coastal Zone Conservation Plan) for the preservation, restoration, orderly development, and enhancement of California's coastal zone.

The most important prerequisite for intelligent land use planning will be the preparation of an integrated inventory and evaluation of the physical and biological characteristics of the coastal region as they

effect various types of land use. In this regard the Forestry Remote Sensing Laboratory (FRSL) of the University of California is conducting a NASA sponsored remote sensing study of the usefulness of aircraft and spacecraft imagery for preparing integrated resource inventories and for monitoring significant changes in the physical and biological environment of the North Coast of California.

The North Coast Test Site encompasses the entire area (10,362 square miles) within the five coastal counties of northern California between San Francisco's Golden Gate and the Oregon border, viz., Marin, Sonoma, Mendocino, Humboldt, and Del Norte. The northern portion of the test site may be characterized as timbered, mountainous terrain where timber harvesting and processing is the mainstay of the economy. The southern portion of the test site contains less mountainous terrain and consists of many developed urban centers and interspersed grazing and agricultural land. The length of coast bordering on the west edge of the test site is 418 miles, or approximately 39 percent of California's coast line. This stretch of ocean coast is rated as the most beatiful in the state.

Remote sensing studies are being performed in two intensive study sites within the North Coast Test Site. The northern study site encompasses a swath of coastal land extending inland some 20 - 25 miles from Cape Mendocino to the Humboldt-Del Norte County line. The southern intensive test site includes the area encompassed by Sonoma and Marin Counties.

4.2.2.2 Objectives

The primary purpose of this investigation is to evaluate the usefulness of remote sensing data in providing general land use planning

information pertaining to the north coast of California, as defined by the North Coast Test Site. It is anticipated that in the process much information of direct benefit to resource managers and developers within the area will be derived. More specifically, the objectives are: (1) to determine the level of accuracy, the time and the costs to prepare a land use inventory using human interpreters; (2) to determine the level of accuracy and detail for classifying significant land use categories using automatic interpretation techniques; (3) to use quantitative test procedures to determine which bands, dates, and combination of bands and dates of imagery obtained by the ERTS-1 system provide the optimum data base for generating land use maps; (4) to determine which of the various biological and physical features that exhibit change over time can be discriminated and monitored; and (5) to determine which remote sensing techniques (e.g., change detection techniques; image enhancement; density slicing; densichron analysis; and Transfer Scope viewing) will be needed to extract useful information from the ERTS-1 and supporting high altitude aircraft data.

A significant undertaking required before these objectives can be attained involves an enumeration of those parameters which are of particular importance to environmental planners in determining the potential of an area in terms of land use, be it natural resource utilization, open space preservation, urban expansion, or industrial development. Interaction between the FRSL and planners currently involved in the formulation of long range land use plans for the coastal region of California is necessary for this undertaking.

The remainder of this report on the North Coast Test Site describes the research activities which have been conducted to satisfy the objectives of the remote sensing project. They include: (a) compilation of a classification scheme which includes the environmental parameters of particular importance to land use planners; (b) human analysis of land use categories in the southern study site and (c) human analysis of resource problems associated with the redwoods in the northern study site using U-2 and ERTS data.

4.2.2.3 North Coast Environmental Planning and Classification Data

One of the objectives of the North Coast Study is to determine the feasibility of using the information obtained from remote sensing as an aid to regional environmental planners for planning the orderly development of this area. In order to accomplish this task, it is necessary to identify the inputs which are or could be utilized in the planning process, and then assign relative weights to these inputs in terms of their significance to the planners' objectives. The next requirement is to compare this weighted list of desired inputs with a list of that information which physically can be derived through the analysis of remote sensing data. This second list should be weighted according to the cost, the time and the level of accuracy associated with generating the desired information from remote sensing data. In this manner, an "optimum" remote sensing system can be developed to assist regional planning. The steps taken to determine the information requirements of regional planners are presented in the remainder of this section.

In an area as large and diverse as the North Coast Test Site, no

one regional planning agency has objectives and data requirements which would satisfy all north coast planners' needs. The agency which most closely met these criteria in the north coast area was a temporary state government body set up from within the Department of Navigation and Ocean Development (the Interagency Council for Ocean Resources) which cooperated with other state resource agencies and county planners in the creation of the California Comprehensive Ocean Area Plan (COAP). The major shortcoming of the data requirements outlined is the plan dealt exclusively with a narrow and sometimes arbitrarily defined area immediately adjacent to the beach or coast (essentially as specified in the Coastal Zone Conservation Act passed after COAP was completed). In order to meet planning needs within the broader North Coast Test Site, additional data requirements must be defined. A comprehensive list of desirable environmental data, see Table 4.9 (applicable throughout the north coast), was compiled after reviewing various planning documents. The primary sources used to develop the list of information needs were:

The California Comprehensive Ocean Area Plan (COAP), 1972. State of California, Department of Navigation & Ocean Development, Interagency Council for Ocean Resources.

Supplement to COAP, 1972. State of California, Department of Navigation & Ocean Development, Interagency Council for Ocean Resources.

California Coastline -- Preservation and Recreation Plan, 1971. California Department of Parks and Recreation (in cooperation with COAP).

Fish and Wildlife in the Marine and Coastal Zone, 1971. California Department of Fish and Game (in cooperation with COAP).

Ocean Coastline Study, 1970. Association of Bay Area Governments (ABAG).

TABLE 4.9. PARAMETERS OF IMPORTANCE TO ENVIRONMENTAL PLANNERS FOR DETERMINING THE POTENTIAL OF AN AREA IN TERMS OF LAND USE.

I. Site Characteristics or Physical Attributes

A. Landforms
- Beaches (rocky and sandy)
- Cliffs, steep slopes, some land slides
- Dunes
- Island
- Mud flat
- Sea stack, rookery
- Spit, bar
- Playas
- Marine terraces
- Swamp

B. Geology
- Parent material -- 9 geologic types on coast of California
- Faults -- monitor seismologic activity -- rank areas for hazard
- Aquifers
- Aquifer recharge areas
- Oil or gas fields, other mineral deposits

C. Pedology
- Soil type } stability (erodibility, compressibility)
- Soil drainage }

D. Physiography
- Elevation, slope (steepness and form), aspect
- Intervisibility
- Exposure (shoreline): protected → exposed
- Access (shoreline): plains, low terrace, high terrace, hills
- Drainage net or pattern (delineate watershed)
- Flood plain

E. Water Bodies
- Open water -- estuary
- Open water -- lagoon
- Lakes and ponds
  - permanent
  - ephemeral
- Reservoirs
  - classify by type of dam } hazard ranking
  - classify by proximity to seismologic areas }
- Rivers and streams (stream order)
- Tidal marsh
- Tidal flat
- Coves, bays
- Deep water access
- Springs

F. Marine Features
- Kelp beds
- Sediment plumes
- Water clarity
- Water temperature
- Waves and currents
- Depth
- Reefs
- Wildlife areas (abalone, fish, seals, otters, birds, etc.)

G. Primary Vegetation
- Species composition
- Density
  - stems/acre
  - percent crown closure
- Timber volumes

Examples of Primary Vegetation Classification

Natural Vegetation (COAP)		Biotic Communities (Calif. Dept. of Parks & Rec.)	Land & Marine Ecology (ABAG)
Barren	Nb	1. Redwood Forest	Vegetative Cover:
Coastal Forest	Nc	2. N. Coast Coniferous Forest	1. Coniferous Forest
Redwood Forest	Nf	3. Maritime Pine Forest	2. Hardwood Forest
Grassland	Ng	4. Mixed Evergreen Forest	3. Grass and Forbs
Hardwood	Nh	5. N. Coast Scrub	4. Chaparral & Mtn. Brush
Woodland Grass	Nj	6. Chaparral	5. Cultivated & Pasture
Kelp	Nk	7. N. Coast Grasslands	6. Barren
Marsh (salt)	Nm	8. Coastal Strand	7. Urban
Marsh (fresh)	Nn	9. Freshwater Marsh	Ecological Features:
Riparian	Nr	10. Coastal Salt Marsh	Extent of Abalone
Coastal Sage	Ns	11. Sandy Intertidal Zone	Extent of Bishop Pine
Cut-Over Redwood	Nw	12. Rocky Intertidal Zone	Cormorant Nesting Areas
Other	Nz	13. Nearshore Zone	Sea Lion Rocks
		14. Urban	Gull Nesting Area
		15. Agriculture	Heron Rookery
			Eel Grass Beds
			Important Fishing Areas
			Clam Beds

H. Other Features or Phenomena
- Vegetation oriented
  - burned over areas
  - clear cuts
    - by tractor
    - by cable
  - insect and pathogen infestations
  - smog damage
  - fuel hazard for fires
  - windthrow along cutting boundaries or within selective logging areas
- Land oriented
  - landslides
  - stream aggradation and other changing stream conditions (e.g., amount of shade for water)
  - areas of tidal inundation likelihood (e.g., from hurricanes)
- Recreation oriented
  - historic/archeologic sites
  - unique sites or situations of high scenic appeal
- Wildlife oriented
  - monitor wildlife herd size
  - identify wildlife herd range and changes in range over time
- Climatic oriented
  - snowfall, fog occurrence (spatially and over time)
- Pollution oriented
  - air -- smoke, dust
  - water -- effluents, sediment loads, thermal
  - noise -- industrial, vehicular (proximity to likely sources of noise)
  - aesthetic -- clear cuts, cut and fill areas, urban blight

II. Land Use

A. Urban and Industrial
- Residential
  - density (families/net acre)
    - 0-1 very low
    - 1-5 low
    - 5-9 low-medium
    - 9-29 medium-high
- Industrial
  - manufacturing and warehousing
  - utility installations
  - extractive (mines, quarries, etc.)
- Military
  - bases and camps
- Commercial
  - business centers
  - urban recreation (bowling alleys, stadiums, race tracks)
- Transportation
  - highways and roads
  - airfields
  - harbor facilities
  - railroads
  - canals
- Institutions
  - universities and hospitals

B. Open Space
- Agricultural
  - intensive -- cultivated or irrigated } could easily be expan[ded]
  - less intensive -- grazing } to include crop types, crop condition, etc.
- Commercial forest
- "Non-commercial forest" (wildland)
- Regional recreation (golf courses, ski areas, parks)
- Other non-developed areas

III. Land Ownership and Land Values

Can the Last Place Last, Preserving the Environmental Quality of Marin, 1971. Marin County Planning Department.

Mendocino County General Plan, Planning Division, Department of Public Works.

Recreation Plan, 1985, Sonoma County Planning Department.

Design with Nature, 1969. Ian L. McHarg.

Natural Vegetation and Land Use Classifications, 1972. Dr. J. Estes, et al, Geography Department, UC Santa Barbara.

Coastal Zone Conservation Act, Proposition 20 Public Resources Code, Section 27000-27650, November, 1972.

Act creating Redwood National Park in California. Public Law 90-545, 90th Congress, s.2515, October 2, 1968.

Environmental Goals and Policy, State of California, John S. Tooker, Director. Office of Planning and Research, Governor's office, March 1, 1972.

Program Design for San Francisco Bay Region Environment and Resources Planning Study, U.S.D.I. Geologic Survey and U.S. Department H.U.D. Research and Technology. Menlo Park, California, October, 1971.

The next step was to acquire "feedback" from the environmental planning agencies which deal with the problems created by the developmental demands being made on the North Coast Test Site. The type of feedback desired included: (a) the suitability of the parameters for environmental planning, (b) the image scales, the frequency of data acquisition desired for each parameter and the relative value of each. Feedback and reaction to the list of parameters for environmental planning was received from county planners, coastal commissions, U.S. Forest Service and U.S. Park Service resource managers and wood products industry personnel.

They grouped their information needs into "areawide" and "sub-area"

levels. These planners and resource managers listed the optimum image scales for obtaining both areawide level and sub-area level types of information as follows:

<u>Optimum image scales for areawide information:</u>

1" = 2,000' to 8,000' (1/24,000 - 1/96,000),

where 1" = 2,000' for display map of a corridor

1" = 4,000' as a suitable format for entire county or planning unit

1" = 8,000' as the suggested format for county atlas, regional perspective and map format

<u>Optimum image scales for sub-area level information:</u>

1" = 1,000' to 3,000' (1,12,000 - 1/36,000)

Concern was expressed over the costs of enlarging remote sensing imagery in order to be of maximum value, but the planners recognized the necessity for analyzing and interpreting remote sensing data at one scale and preparing and displaying maps at yet another scale.

The planners and resource managers also provided a listing of basic information for regional planning. This included topography (e.g., slope categories and drainage patterns), soil type (e.g., stability and erodibility), vegetation types (e.g., timber, grass, brush, and marine), and geology (e.g., landslide and fault hazard areas). Also included were intervisibility (determination of area visible from any given vantage point) and the location of rare and/or endangered biotic communities or species.

A list of environmental parameters was prepared which planners felt

should be monitored either periodically (mostly on an annual basis) or on short notice. The parameters which could be evaluated by remote sensing included: Land use by slope classes; amount and type of development on unstable soil or subject to flood or fault hazard; annual amount of agriculture gone out of production; annual increase in developed land by category (e.g., residential, commercial, etc.); and areas of importance to environmental quality.

On the whole, the planners felt that the compilation of inventory data in Table 4.9 was desirable and beneficial for improved planning and management.

Having generated a complete listing of the important environmental parameters in the north coast, we recognize that it remains for image interpreters and remote sensing data analysts, to determine the feasibility of providing information regarding those parameters in the desired format, within the desired time frame and for the desired cost. It is envisaged that the list of environmental parameters will serve as the basis for a workable classification scheme and as the basis for determining which resource can be identified on the different types of aircraft and spacecraft imagery. Interfacing a desirable classification scheme for the remote sensing data with the information requirements of regional planners is one of the major tasks involved in remote sensing system development.

4.2.2.4 Manual Analysis of ERTS-1 and Supporting Aircraft Data in the Southern Intensive Study Area

Description of Study Area: Sonoma and Marin Counties

Sonoma and Marin counties comprise the southern intensive study area within the North Coast Test Site, and occupy an area of approximately 1,344,000 acres (2,100 square miles) immediately north of and adjoining San Francisco Bay, California. This area is complex in both physiography and land use and includes considerable forest, range, pasture, and agriculture (vineyards, apples and feed crops) land. It is dissected by two major river systems, (the Russian and the Petaluma), and it fronts on both the Pacific Ocean and San Francisco Bay. The impact of population pressure is felt in this area as increased urbanization and transportation networks spread along the north bay shore of Marin County and the interior valleys of Sonoma County. Increasing pressure among user groups for more land preserves or more development (in single units, large developments, large private holders or state owned land), makes accurate land use inventory, monitoring, and planning a necessity.

For this reporting period, two types of analysis of remote sensing data were performed of Sonoma County (see Figure 4.13): (1) July ERTS and U-2 imagery of Sonoma County were compared to determine their usefulness for mapping land use categories and (2) several dates of ERTS imagery of Pt. Reyes National Seashore in Marin county were studied to determine how seasonal changes affected mapping accuracy. Several ground truth cells of approximately four square miles, representing differing land use, were located throughout the study area. Ground photographs were taken in conjunction with ERTS-1 overflights (July 7 and 11 and August 31) for verification of interpretations made on the

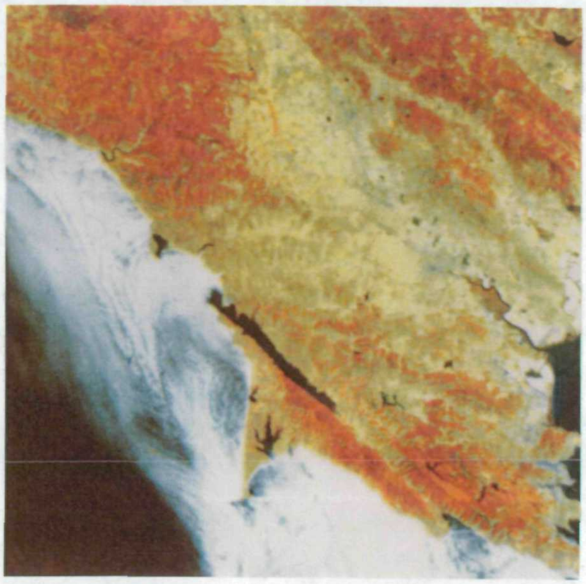


Figure 4.13. This ERTS-1 color composite image (July 27, 1972) of Sonoma County, California illustrates the delineation and classification of homogeneous appearing areas. The text contains explanations and analyses of 23 land use vegetation/terrain type classifications applied to this region of the North Coast Test Site.

satellite imagery and U-2 photography. To complete the sampling, excellent U-2 photographs (scale 1:130,000 and 1:445,700) of the study area were obtained by the NASA/Ames U-2 aircraft on July 5, 1972, October 6, 1972, and January 4 and April 4, 1973.

The objectives for analyzing ERTS-1 and high altitude aircraft data are to determine (1) what environmental or land use parameters can be delineated and classified on ERTS-1 imagery, and (2) to what degree identification of these areas is possible on ERTS-1 alone and with the aid of supporting aircraft and ground truth data.

Material Examined

ERTS-1 imagery available for evaluation and interpretation during this study period included:

7/27/72	generally clear, except along coast
8/13/72; 8/14/72	clear
9/1/72	20 percent cloud cover
9/19/72	50 percent cloud cover, scattered cumulus
10/7/72	90 percent cloud cover
10/25/72	clear -- positive transparencies very dense
11/12/72	30 percent cloud cover
11/30/72	40 percent cloud cover
1/5/73	clear

The July 27, 1972, ERTS-1 imagery of Sonoma County was selected for the initial interpretation of regional land use categories for the following reasons: (1) good quality imagery was available for interpretation and for making color composite images, (2) Sonoma County was virtually

cloud free, (3) ground data were collected near the time of the ERTS-1 overpass, the (4) a U-2 high altitude flight (72-110) occurred close to the date of the ERTS-1 overpass.

In addition, 70 mm and 9 x 9 inch color infrared aerial photographs were obtained by the U-2 aircraft on July 5 and October 6, 1972. The July imagery was of very high quality and covered the eastern portion of Sonoma County. The aerial photography taken on October 6 provided coverage of the western half of the county. This high altitude photography (65,000 feet) provided the data against which the delineations and classifications made on ERTS-1 imagery from July were compared.

Procedures

The first step taken during the analysis of the ERTS-1 imagery of Sonoma County was to review the parameters for environment planning described in the previous section (Table 4.8). This review revealed that many of the informational requirements of regional planners could not be satisfied with the level of information extractable from ERTS-1 imagery. Their needs would be better served by high altitude photography of higher resolution (as provided by the U-2 aircraft). It was felt, however, that generalized land use and vegetation/terrain maps could be prepared from the satellite imagery. These generalized maps could be of considerable value in less developed areas requiring a more general classification scheme.

The second step in the analysis was to delineate the homogeneous areas visible on the ERTS-1 imagery. For this purpose, black-and-white ERTS-1 imagery from MSS bands 4, 5, and 7, was delineated based upon

the tone, texture, and location of features. A diazochrome color composite, simulating a false-color infrared image, was prepared using three MSS bands; the composite was made by superimposing band 4 reproduced on yellow diazochrome film, band 5 reproduced on magenta diazochrome film, and band 7 reproduced on cyan diazochrome film. Then using color, texture, and location of features as clues, homogeneous areas were delineated and classified on the color composite.

The third step was to compare the delineations made on the ERTS-1 color composite with the high altitude photos taken on July 5 and October 6. To facilitate this comparison, the delineations made on the ERTS-1 color composite were transferred directly to the U-2 high altitude imagery by means of a Zoom Transfer Scope. Finally, the high altitude color infrared photographs were interpreted to verify the delineations and classifications made on the ERTS-1 color composite and to establish the true identity of many of the units delineated.

Results of the Analysis of the ERTS-1 Color Composite

Figure 4.13 shows the ERTS-1 color composite with the homogeneous units delineated. A description of each of these mapped areas appears in Table 4.10. These descriptions are based primarily upon analysis of high altitude photography and ground data, rather than on interpretation of the ERTS-1 composite. The analysis of the ERTS-1 composite revealed that only a limited number of categories could be accurately or consistently identified, although the delineations, themselves, coincide quite closely with different land and environmental categories.

In general, healthy vegetation categories could be identified and

TABLE 4.10.- DESCRIPTION OF MAP UNITS DELINEATED ON THE ERTS-1 COLOR COMPOSITE IMAGE

1. Forest: greater than 95% vegetated (based on proportion of ground area obscured by vegetation in the vertical view); little bare soil and/or rock outcrops, mountainous terrain. Species include canyon live oak, California black oak, bigleaf maple, madrone, red alder (California white oak and blue oak restricted to eastern county).

2. Forest: greater than 98% vegetated, little or no bare soil or rock outcrops, restricted to northern coastal hills. Species include a mixture of hardwoods and young conifers: bigleaf maple, madrone, bishop pine, tan-oak, Douglas fir, red alder, redwood.

3. Forest/Grassland: up to 10% open grassland and/or rock outcrops, mountainous terrain. Species composition similar to 1 above, increased open grassland being the major difference.

4. Forest/Grassland: 50-60% open grassland, in general occupying drier inland sites and mountainous terrain. Species composition Douglas fir, madrone, tan-oak, chinquapin.

5. Forest/Grassland: Grassland up to 20% total area, northern county, mountainous terrain. Some commercial conifers including Douglas fir, sugar pine; other species include tan-oak, chinquapin and oaks.

6. Forest/Grassland: Occupies inland mountainous terrain. Species composition similar to 4 above, but with less open grassland (less than 20%).

7. Forest: 90% commercial conifers; grassland less than 10%. Some coastal influence affects species composition (e.g., of bishop pine, Douglas fir, and redwood).

8. Agriculture: young orchard area along stream margin.

9. Agriculture: mixed agriculture on river valley flood plain, generally small fields, including dry and irrigated pasture, alfalfa.

10. Agriculture: large fields formed on reclaimed land, mature or harvested in July, thereby appearing bright white.

11. Agriculture: smaller fields planted to feed grains, scattered small orchards and residences.

12. Agriculture: Napa Valley vineyards.

13. Agriculture: primarily apple orchards located on river terraces.

14. Grassland/Brush: coastal chaparral type.

15. Grassland/Pasture: associated with interior foothills, dairy farms predominate.

16. Grassland/Pasture: similar to 15 but having less dairy farms, slightly drier sites than 15.

17. Grassland/Woodland: interior foothills, annual grassland are predominant on slopes while oaks dominate in drainages and on hilltops.

18. Oak/Chaparral: oak more prevalent than brush types. Species include California white oak, California black oak, Oregon white oak, canyon live oak, California live oak.

19. Chaparral/Oak: chaparral-hardwoods in approximately equal proportions. Species similar to 18.

20. Marsh: saltwater marsh. Species include pickleweed.

21. Urban:

22. Area of Little Vegetation: serpentine soil, burned area, limited extent.

23. Bottomland: along river, riparian vegetation present, limited extent.

differentiated from dry or unhealthy vegetation types. That is, forest and shrubland types could be distinguished from dry rangeland types. Differences within the healthy vegetation category attributed to plant density were readily apparent and delineated. Major river systems, specific urban complexes and agricultural land (see Table 4.10) were also among the broad categories which could be identified directly on the ERTS-1 color composite. With the aid of high altitude U-2 photography and a limited amount of ground data, all the categories (map units) delineated on the ERTS color composite were identified.

The 23 separate descriptions fall into eight general categories: forest, agriculture, grassland and grassland/woodland, chaparral or scrub, marshland, riparian, urban, and barren. As such, they conform to many of the general categories which appear in the classification schemes produced by COAP, ABAG and the State Parks system. The amount of detail required by these schemes, which varies, is often met by the sub-classifications -- as mapped on the ERTS-1 color composite image. For more accurate or refined vegetation typing, including species identification and determination of land use practices, high resolution imagery, accompanied by some sampling on the ground is essential.

Figure 4.14 shows three examples of U-2 imagery provided by NASA/Ames. The delineations appearing on these photos are those transferred from the ERTS-1 color composite image by means of the Zoom Transfer Scope. Note that these delineations are easily compared with the actual ground features seen on the U-2 photos. It should be apparent that there is good correlation between the delineations of land use and vegetation/terrain types

A B C

Figure 4.14. These U-2 false-color infrared photographs of Sonoma County illustrate the technique used to evaluate interpretation results derived from ERTS-1 imagery. Delineations and classifications made on the ERTS-1 imagery have been accurately plotted onto the U-2 photographs using a Zoom Transfer Scope. Consequently, boundary placement and type of identification are easily evaluated when positioned on the high definition U-2 photos. Note that photo "A" illustrates mainly forest classifications. Photo "B" shows the cities of Santa Rosa and Petaluma surrounded primarily by agriculture classifications. Additional agricultural classifications surrounded by grassland-shrub-woodland types are illustrated in photo "C". The classification symbols appearing on these photos are explained in Table 4.10.

made from the ERTS-1 color composite image and the features seen on the aerial photos. Accurate identification for the majority of the mapped units, however, was possible only with the aid of the higher resolution aerial photographs. For a few of the mapped units, large scale photographs and ground data were required to provide accurate identification. As can be seen on Figure 4.14-A, there is good coincidence between the ERTS-1 and high altitude images for the mapped areas of forest. However, in order to accurately identify the various categories of forest land (types 1-7 in Table 4.10) high resolution images or ground data were required. The sub-classifications within the forest class are based mainly on varying proportions of open space and woody vegetation. Forest categories (1-7), however, could not be accurately differentiated from other vegetation types such as riparian (23) and shrub-chaparral (14, 18, 19) on the ERTS-1 composite image.

Agriculture categories (8-13), however, could be identified and differentiated from other categories on the ERTS-1 image. A comparison of types 9 and 11 (See Figure 4.14-B, C) suggests that subtle differences between agricultural land categories are related to field size. In addition, the relative amount of irrigated pasture in an agricultural area could be detected on ERTS-1 imagery. The stratification and identification of different agricultural types could be improved by mapping at a more desirable seasonal state using a multidate approach.

In Figure 4.14-C, the transfer of data from ERTS-1 to the U-2 photo shows that grassland and grassland/woodland types can be accurately mapped. Interpretation of the U-2 photo shows that the differences in

the ERTS classifications were due to relative density differences in the grassland (15), grassland/oak (16), and brush and oak (17) types. The ERTS-1 image appears to have adequate detail for the differentiation of types 15 and 16. The July seasonal state is excellent for distinguishing grassland, now dry, from healthy, green vegetation types.

Figures 4.14-B and 4.14-C show the capabilities of ERTS-1 for allowing discrimination of shrub-chaparral types. While these categories can be mapped separately, they tend to be easily confused with forest types. Therefore, higher resolution imagery is required to consistently differentiate these categories.

Marshland (seen on Figure 4.14-C), is easily delineated on the ERTS-1 imagery and can be classified separately from all other categories. Its proximity to the estuary makes the identification of this category possible, although absolute verification is possible only with the aid of the U-2 photography.

Several urban centers can be seen on Figures 4.14-B and 4.14-C. The perimeters of the urbanized areas blend into adjoining dry grassland and pasture and are difficult to map accurately on ERTS-1 imagery. The urban centers, however, are visible as separate entities and can be identified as "urban" on the ERTS-1 imagery. The July ERTS-1 imagery is not the optimum one for classifying urban areas which are bordered by dry grassland and dry land agriculture -- later in the year these adjoining areas will turn green and will contrast sharply with urban areas on images taken in the red band (e.g., MSS number 5).

The category of barren areas (22) refers to those areas which appear

to be devoid of vegetation or which do not conform in appearance to other natural categories. One example in the northern part of Sonoma County is a region of serpentine soil which has a sparse covering of vegetation. Another example of barren land is an area in the southern part of the county. It can be seen in Figure 4.14-C and appears to be a brush/oak mixture which was burned by a wildfire sometime after the U-2 imagery was taken on July 7 and before the ERTS-1 imagery was taken on July 27.

The riparian vegetation mapped on Figure 4.14-B occurs along a stream course and though accurately mapped on ERTS-1, it could not be consistently identified in other areas on this type of imagery alone.

Table 4.11 summarizes the findings of the comparative analysis of the ERTS-1 color composite image and the U-2 photography for those categories which were initially mapped on the ERTS-1 color composite image. It should be apparent from this table that many wildland and cultural features (categories) can be accurately delineated on an ERTS-1 image, but only a few can be accurately identified. Most of the mapped categories could be identified using U-2 photography. These analyses also revealed that certain categories could be identified because of their seasonal appearance in July. It is recognized that still other categories will be identifiable because of their seasonal appearance at other dates.

Results of the Analysis of the Multidate ERTS-1 Color Composites of Pt. Reyes

ERTS-1 color composites from three dates (July 25, 1972, October 25, 1972, and January 5, 1973) show Pt. Reyes National Seashore in three distinct seasonal states. Analysis of the ERTS images was performed to

TABLE 4.11. IDENTIFICATION OF MAPPED UNITS
ON ERTS-1 AND LARGER SCALE IMAGERY TAKEN DURING ONE SEASONAL STATE

Categories from Table 1 Delineated on ERTS-1 Color Composite Image	Categories Identifiable on an ERTS-1 Image. (Single Date)	Categories Requiring U-2 or Larger Scale Imagery for Identification
Forest		X
1		X
2		X
3		X
4		X
5		X
6		X
7		X
Agriculture	X	
8		X
9		X
10		X
11		X
12		X
13		X
Grassland & Grassland/ Woodland	X	
15	X	
16	X	
17		X
Shrub-Chaparral		X
14		X
18		X
19		X
Marsh		X
20		X
Urban		
21	X	
Barren		
22		X
Riparian		
23		X

determine if the phenological differences would improve the accuracy of delineating and identifying the important plant communities associated with the National Seashore. A vegetation type map of all plant communities (prepared from U-2 photography and checked on the ground for accuracy) on Pt. Reyes was used to compare the accuracy of the mapping on the ERTS color composites. Mapping from the ERTS composites was based upon color and texture.

Preliminary results indicate that the July imagery is best for separating the grassland communities from the scrub and forested plant communities. This delineation is possible because the grassland vegetation is dry in July in contrast to the healthy green foliage of scrub and forest vegetation. Later in October and January, the grassland vegetation has turned green thus reducing the contrast between this type and others it is associated with. Hardwood vegetation found associated with drainages was most accurately delineated on the July ERTS image. On the latter dates of ERTS imagery, the hardwood foliage had either turned brown or had dropped. A fog bank obscured this area on the July ERTS imagery. Scrub-grassland communities and confer-scrub communities were best delineated on the October ERTS imagery. Numerous man-made reservoirs which trap surface runoff for cattle drinking water, could not be resolved on any of the ERTS images examined. Most of these reservoirs are less than one acre in size. In summary, only gross vegetation boundaries could be delineated on the ERTS color composites taken during three different seasonal states. Because of the low resolution of the ERTS composites it appears that phenological changes in the

vegetative condition did not significantly aid in the delineation of plant communities. Of the three ERTS images examined the July or October images were judged the best for plant community mapping. Unfortunately, the level of detail in mapping was not sufficient to be of much use to Park Service or Coastal Commission personnel for planning or management purposes. (Illustrative materials and maps generated in this study will be reproduced in the final ERTS-Type III report, dated December, 1973).

4.2.2.5 <u>Analysis of Wildland Burned Areas on ERTS-1 Imagery</u>

<u>Introduction</u>

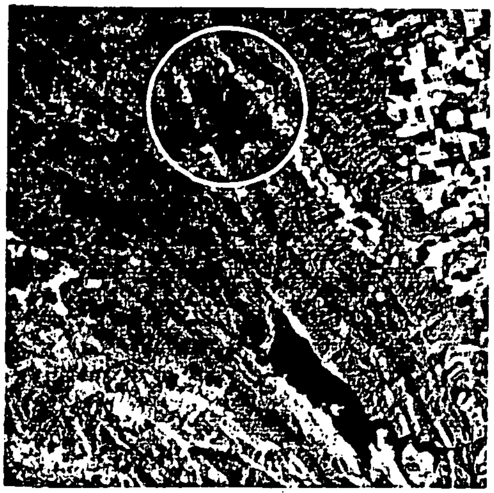
This section discusses the analysis of ERTS imagery for fire damage assessment of a large wildfire which occurred in an area adjacent to the southern study area of the North Coast Test Site. Although the fire did not occur within the Test Site, the fire did consume vegetation types and threaten resources which were similar to those found within the Test Site. Hence, the analysis is presented here to illustrate the potential and practical uses of ERTS imagery for evaluating fire damage within the North Coast Area.

<u>Procedure</u>

The perimeters of the Pocket Gulch and Fiske Creek fires were mapped on an ERTS black-and-white infrared transparency (MSS band number 7), acquired on July 27, 1972, approximately 10 days after the suppression of both fires, (see figure 4.15). The fire perimeter map was made using the Forestry Remote Sensing Laboratory scanning microdensitometer and computer capabilities, and was compared with the map produced by the California Division of Forestry (CDF) using conventional techniques.

A. (Scale = 1:125,000)

B. (Scale = 1:110,000)



C. (Scale = 1:780,000)

D.

Figure 4.15.

A. California Division of Forestry (CDF) map of Fiske Creek (left) and Pocket Gulch (right) burns. CDF estimates of area burned were 60 acres and 10,340 acres respectively.

B. Map of Fiske Creek and Pocket Gulch burns prepared by the Forestry Remote Sensing Laboratory from a single band black-and white ERTS-1 image, as shown in C. Perimeter detail and information about damage levels within the perimeter are increased here relative to the CDF map in A.

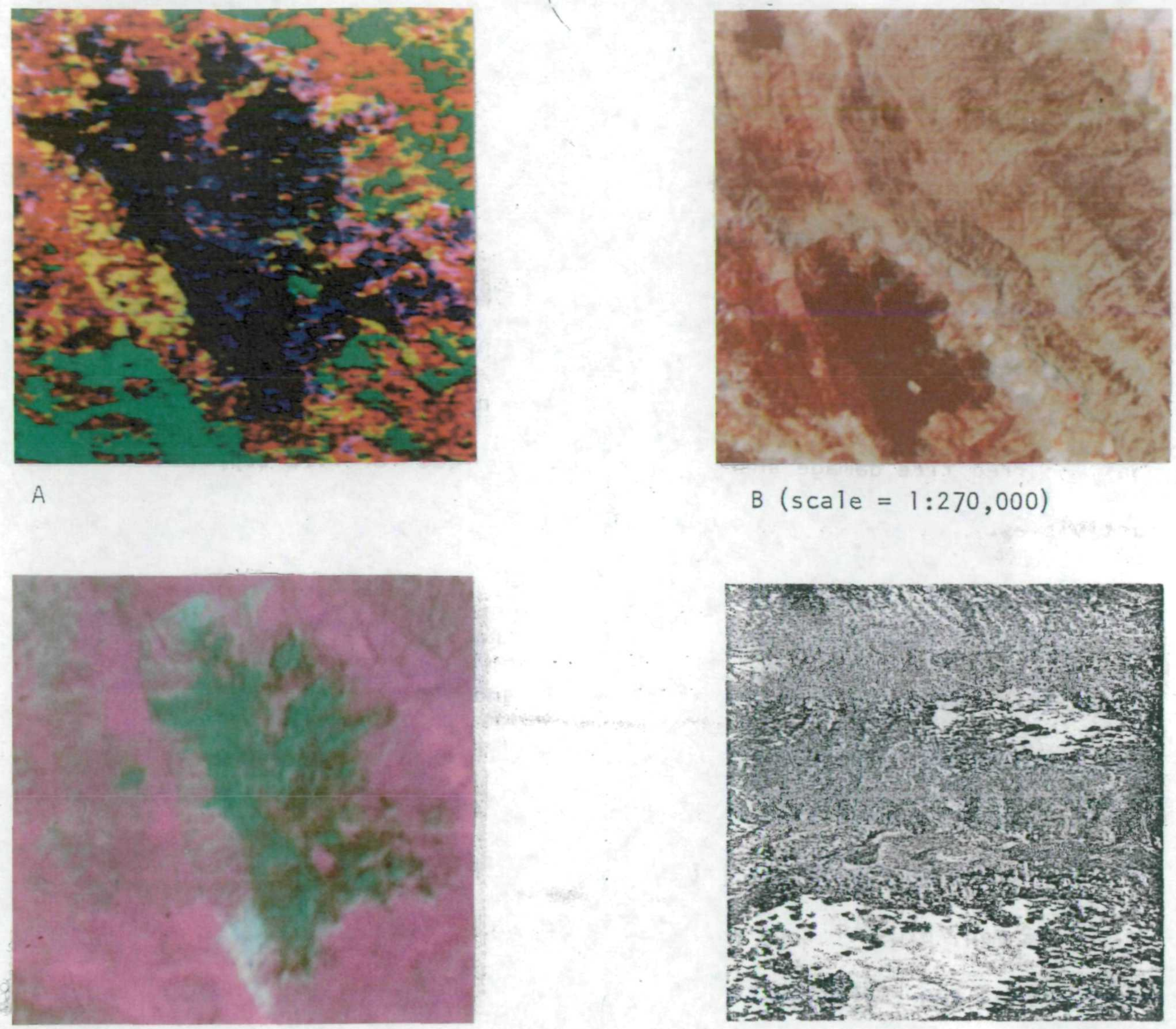
C. Portion of ERTS-1 MSS band 7 image taken on July 27, 1972. Enlargement of this image was used to create map in B.

D. Low altitude oblique photo showing the small Fiske Creek burn. Camera is looking towards the south as indicated by annotation 1 on Figure B.

Conventionally produced fire perimeter maps are made by individuals who walk or drive around the fire perimeter and draw the boundaries on a topographic map sheet. In the case of very large fires, low flying aircraft or helicopters are employed and an individual draws boundaries by hand directly on a map sheet. A typical map appears in Figure 4.15 and are used almost exclusively for determining the location and acreage burned by the wildfire. This information is needed to determine who has incurred fire damage and who should be charged for fire suppression activities.

Results and Discussion

Figure 4.15-B shows the perimeters of the Pocket Gulch and Fiske Creek fires as drawn from the ERTS-1 image and using the FRSL scanner/computer system. The CDF and ERTS-1 maps differ significantly. Estimates of the overall burned area were 10,340 acres and 13,340, respectively. The CDF spent approximately 4 to 8 hours (including flying the fire to draw the map, plus time to use a dot grid for area estimation), or about $500 to map the Pocket Gulch burn. Forestry Remote Sensing Laboratory personnel spent about 25 minutes (after the image was in hand) or about $50 to map the same burn. Low altitude oblique aerial photography (see Figure 4.15-D and Figure 4.16-D) indicates that the fire perimeter map produced by the FRSL is more accurate than that prepared by the CDF. More significant than the improved mapping of the fire perimeter is the additional capabilities provided by ERTS-1 imagery to map the interior of large burned-over areas in detail and to monitor burned areas over time to evaluate vegetative regeneration.



A

B (scale = 1:270,000)

C (scale = 1:185,000)

D

Figure 4.16.

A. CRT output from the FRSL's CALSCAN automatic image classification process, using MSS bands 4, 5, and 7 from ERTS-1 data tapes, showing the Fiske Creek and Pocket Gulch burns.

B. NASA color composite, MSS bands 4, 5 and 7, showing the same burns.

C. Change detection enhancement made by the FRSL using the diazochrome composite process showing a control burn (9/15/72-9/18/72) on southwest edge of original Pocket Gulch wild fire (7/17/72).

D. Low altitude oblique showing the unburned grass and orchard "island" within the Pocket Gulch fire perimeter. Camera is looking towards the northwest as indicated by annotation 2 on Figure 4.16-B.

Figure 4.15-B also shows interior delineations which correspond to those areas within the main fire perimeter where little or no fire damage occurred. These delineations were made by a human interpreter using the X-Y coordinate recording scanner and computer facilities at the FRSL.

Interior delineations of the burned area can also be made using automated classification techniques. The FRSL's computerized system processed three bands (MSS bands 4,5 and 7) from ERTS data tapes using its CALSCAN automatic feature classification routine, which then displayed on a color cathode ray tube (CRT) what is seen in Figure 4.16-A. In addition to the classified image generated by CALSCAN, tabulated statistics are provided for each classified category, enabling ready computation of all relevant areas. A direct comparison of the multiband (4,5 and 7) color composite in Figure 4.16-B with the multiband classified enhancement in Figure 4.16-A can not be made because the latter shows the result of point by point classification (from magnetic tapes) based on selected training samples whereas the former is an unclassified ERTS-1 color composite image which portrays the wildfire and all the variables of topography, vegetation and degree of burn associated with it.

Classified maps such as have been discussed here aid in more accurate damage assessment, better planning for salvage logging in timbered areas, improved post-fire revegetation programs (where speed is essential to insure that aerial applications of seed get through loose ashes before a rain), and rapid post-fire fuel hazard evaluation.

The change detection capability of an ERTS-based remote sensing system is illustrated in Figure 4.16-C. The dark green color shows the burned area of the original fires (Pocket Gulch and Fiske Creek, July 17, 1972), and the whitish area signifies a change in the perimeter of the fire as detected by the September 18, 1972, ERTS pass. The multi-date enhancement shown in Figure 4.16-C was made using the diazochrome composite process. When the CDF was contacted, it was learned that a private land owner had conducted a control burn on his property (from September 15 - 18) to improve grazing potential, using the west edge of the Pocket Gulch burn as one fuel break. The CDF on-the-ground estimate of the new acreage burned was 2200 acres. Analysis of the ERTS imagery shows this estimate to be too large. Detection of the new burn is just one example of change which can be detected between passes by the satellite. As revegetation of the burn progresses (both the September 15 control burn and about half of the Pocket Gulch burn have been seeded to grass), it will be monitored and evaluated with the aid of the sequential ERTS-1 data.

The post-fire mapping of burned wildland areas is important for many reasons, and tens of thousands of these fires occur annually across the United States. Consequently, it appears certain that the use of sequentially procured ERTS-1 data, rather than conventional mapping procedures, can provide superior post-fire maps, at more frequent intervals and with greatly reduced manpower requirements and costs.

4.2.2.6 Manual Analysis of ERTS-1 and Supporting Aircraft Data in the Northern Intensive Study Area of the North Coast Test Site

Introduction

The northern intensive study site includes the relatively undeveloped land between Cape Mendocino and the Del Norte-Humboldt County line. Included within this forested area which extends approximately 15 miles inland are Humboldt Bay and two metropolitan areas of Eureka and Arcata. Analysis of remote sensing data has concentrated on the timbered land within the drainages of Redwood Creek. Several reasons can be cited for selecting this area for intensive study: (1) The area includes both privately and publicly owned timberland, held within the Redwood National Park; (2) national and even international attention has been focused upon this area during the establishment of the Redwood National Park, and there is great public concern in the management of the land within and adjacent to the park boundaries; (3) Redwood National Park personnel are authorized by Public Law 90-545 to assure that the consequences of forest management and land use on lands adjacent to the Park do not adversely effect the resources within the park; (4) Park Service personnel have elucidated many management problems which can be assessed through judicious use and analysis of remote sensing data; and (5) the area contains forest vegetation types and management problems which are unique.

The primary objectives for our remote sensing studies in the northern study area are to work cooperatively with resource planners and managers (e.g. forest products industry personnel, Park Service, Water Quality

Control Board, North Coast Commission, etc.) to (1) demonstrate the usefulness of supporting high altitude aircraft photography and ERTS-1 spacecraft imagery for preparing inventories of resources, monitoring changes in the resource base, and providing resource information for planning and management purposes; (2) determine the extent to which aircraft or spacecraft imagery can locate potential and existing problem areas, e.g. unstable soil, natural or induced erosion or slides, loss of tree vigor; and (3) to determine the specifications for a practical remote sensing system which would assist in resolving resource management problems.

Procedure

Three related analysis tasks have been performed in an effort to determine the utility of remote sensing data for evaluating resources within the redwood timberland of northern California: (1) Existing black-and-white aerial photos of conventional scales (1/10,000 to 1/20,000) were examined to reconstruct a history of harvesting patterns within a portion of Redwood Creek. The dates of the conventional photographs included: 1936; August, 1962; December, 1966, April, 1968, and March, 1972. Smallscale color-infrared aerial photographs were obtained on April, 1972, July, 1972, October, 1972, January, 1973, and April, 1973. These photos provided the opportunity to demonstrate the usefulness of aerial photographs for monitoring the location of recent harvesting activities and for determining the area of harvested timberland within the Redwood Creek drainage within the past year. (2) The existing small scale color-infrared aerial photography, (1,120,000)

previously indicated has been used as a data base for displaying inventory information and potential resource problem areas. Because this aerial photography has been obtained during the four seasonal stages, it has provided an opportunity to determine how seasonal changes in the resource base effect the accuracy of detecting and identifying physical and biological resource parameters. The small scale aerial photographs (obtained using the NASA U-2 aircraft) provide sufficiently broad coverage per photo and sufficient detail to be excellent for comparison with ERTS-1 images. (3) Multidate ERTS-1 color composites were prepared for three dates of cloud-free weather for the North Coast (October 27, 1972, March 2, 1973 and April 6, 1973). These composites were studied to determine their value for monitoring changes in the resource base and as a base for displaying regional vegetative cover and topographic and slope information.

Results

Harvesting History

The conventional aerial photographs taken periodically back to 1936, were valuable for determining the approximate time the initial timber harvesting had occurred in previously uncut stands of redwood and douglas fir. The exact date of harvesting could not be determined from the photographs because of the time interval between the dates of existing aerial photographs. Although it was readily apparent when initial harvesting had commenced, it was more difficult to determine when and where reharvesting of stands occurred. Reharvesting occurs when a selection system of tree removal is employed. Under this system

a minority percentage of the trees are removed initially, followed by additional selective tree removal at subsequent dates. For the most part, the aerial photographs were also useful in determining the type of tree removal system employed, be it selective harvesting of complete removal of the stand, and the technique for removing the downed timber once it had been cut, be it by tractors which are used on the relatively gentle slopes or high-lead cable which is used in relatively steep topography. The importance of knowing the technique of tree removal is related to the amount of disturbance of the soil and associated vegetation.

The small scale U-2 color-infrared aerial photographs obtained during four seasons in 1972 and 1973, also showed where harvesting activity was occurring and the proximity of other activities and resources with respect to the harvesting. Through prior knowledge of the timber volumes associated with the different timber stands in the area it is possible to estimate the amount of timber removed for a given time interval. The ERTS color composites were sufficiently detailed to show the major cutover areas within Redwood Creek. However, the resolution of the images was not sufficient to detect areas where selective harvesting was being initiated or where reharvesting was occurring within previously disturbed stands. It would also be difficult to make an accurate visual estimate of the amount of area newly harvested despite the fact that newly harvested areas (those which the trees were completely removed) could be detected.

Preparing Inventory Information and Detecting Potential Problem Areas

The U-2 color infrared images were ideal for displaying existing inventory information regarding the timberlands within Redwood Creek. Enlargements of the U-2 photographs provided sufficiently large coverage and detail to be very valuable as a base map over which maps of soils, timber volume, vegetation type, slope data, etc. were overlain. The value of the U-2 photograph lies in its pictorial representation of the physical and biological attributes of the timberland environment and of the relationships of various vegetation-soil types in relationship to each other. The U-2 photographs (original scale of about 1/120,000) were enlarged approximately three and a half times to a new scale of approximately 1/30,000 and were judged excellent by forest products industry personnel for planning road locations, timber harvesting sites, and stand improvements. In addition, they were judged very good by Park Service and forest industry personnel for assessing characteristics of the watershed which represented potential problems to watershed stability.

Using the U-2 photographs for reference, the ERTS color composites were analyzed for their potential in supplying inventory and change detection information. Whereas the ERTS composites provide coverage of the entire region on a single frame, and show gross seasonal changes, for example the distribution of snow cover, changing reflectance characteristics of the tree species, changing patterns of sediment release from Redwood Creek into the Pacific Ocean, they are not sufficiently detailed to be of value to Park Service personnel, forest products industry

personnel or North Coastal Commission personnel. These planners and resource managers require the level of detail and ultimately the kind of information which can be extracted from U-2 photographs which range in scale from 1/120,000 to 1/30,000. (Examples of multidate images of U-2 and ERTS composites for the Redwood Creek area can be seen in the Final ERTS-1 Type III Report entitled, An Integrated Study of Earth Resources in the State of California Based on ERTS-1 and Supporting Aircraft Data, Dec. 15, 1973; Space Sciences Laboratory, University of California, Berkeley.)

Conclusions

Analysis of remote sensing data (including U-2 photography and ERTS-1 imagery) of the North Coast Test Site has been responsive to the mapping and monitoring of environmental parameters which have been designated as important by planners and resource managers in the North Coast. Without exception, county planners, Forest Service and Park Service personnel, Coastal commissioners, and forest industry personnel can utilize the information extracted from color-infrared aerial photography, acquired at 65,000 feet by the U-2 aircraft, to better plan and manage their resources. The aerial photos obtained at an original scale of 1/120,000 provide sufficiently broad coverage to show regional relationships, while the aerial photos obtained at an original scale of 1/30,000 provide the detail necessary for mapping, classifying, and detecting resources and resource problems. The ERTS-1 composites while showing broad regional coverage show only gross resource boundaries and insufficient detail regarding each resource to be useful in day to day management

activities. The ERTS composites have been used for gross vegetation mapping, fire damage assessment, and for monitoring short term changes in the harvesting patterns of the redwood region. The most promising application of Analysis of ERTS imagery in the North Coast Test Site appears to be for fire damage assessment. The timely information provided by ERTS imagery can greatly improve the accuracy of assessment of burned acreages and the location and extent of fire damage within the perimeter of the fire. The user groups most interested in this information are those charged with fire suppression activities within the state (viz. California Division of Forestry, U.S. Forest Service, and the Bureau of Land Management).

4.3 FUTURE PROPOSED WORK

4.3.1 Analysis Within the Feather River Watershed

4.3.1.1 Vegetation/Terrain Mapping

Future remote sensing research within the Feather River Watershed region will continue to concentrate on demonstrating the application of manual and automatic data analysis. Upon completion of the Feather River regional vegetation/terrain resource map, a major objective will be to compare it with regional ground control maps. This will aid in determining the distributional relationships between vegetation types and soils, lithologic geology, elevation, precipitation and other environmental parameters. This base map will also be suited to aid in the testing of automatically processed ERTS-1 data. In addition to the Davis Lake and Bucks Lake areas which are presently being intensively studied, sites such as the Oroville Reservoir and Lake Almanor sub-regions have been

selected for future interpretation testing. Image enhancement techniques which will be applied to ERTS-1 imagery within the sites mentioned will include multidate enhancements using the diazochrome process, new photographic reproduction techniques, and/or other optical or electronic color-combining procedures.

In addition, an attempt will be made within the Feather River Watershed to demonstrate the "operational" utility of ERTS-1 imagery for mapping (manually) a large regional area. This work is being designed to show <u>level of accuracy</u>, <u>time requirements</u> and <u>costs</u> associated with doing the job operationally (which will include field checking and map compilation). It should be noted, however, that the real value of doing this operational task is apparent only when accuracy, time and cost figures can be compared with similar figures associated with previously completed projects having similar mapping objectives -- such as the California Comprehensive Framework Study which Robert Weaver from the California Division of Forestry helped prepare (Mr. Weaver attended our recent workshop held at the FRSL).

The Automatic Image Classification and Data Processing Unit within the Forestry Remote Sensing Laboratory has several hardware and software projects that are now operational and which will be applied to ERTS-1 imagery taken over the Feather River Watershed region:

Hardware

color display system

Software

ERTS to local reformation

intensive test site data extraction

spectral training data extraction

CALSCAN modification

The color display portion of the FRSL computer facility is also now operational. This display allows the storage and viewing in color of up to 3 bands of digital tape images in common register. As an integral part of the computer system, the display can handle line drawings, ERTS-1 images, CALSCAN output images, and scanner images. The operator has control of the input to each of the color guns in the color TV monitor. Thus, he can display simulated CIR images, real-color or other false-color images.

In order to reduce the cost of computer processing ERTS-1 data, several pre-and post-classification steps are performed on the FRSL "mini" computer. The following steps can be taken: (1) the original NDPF tapes are reformatted to local standards, (2) the intensive study areas are selected from the bulk tape, (3) spectral training data are extracted from the intensive study sites, and (4) classification results are displayed on the color display. Further examples of the capabilities of this computer system will be demonstrated in the Dec. 1973 semi-annual progress report.

Lastly, a major effort is planned within the Feather River Watershed which will relate to the "operational" uses of computerized classification techniques. The emphasis in this planned work will be on relating it to a well defined "user requirement" -- in this case, timber volume estimation. Specifically, an attempt will be made to estimate

timber volume for the entire 1.1 million acres within the Plumas National Forest using (1) CALSCAN output showing commercial coniferous forest (possibly divided into three separate volume classes) versus everything else (i.e., water, bare ground, urban, etc.) and (2) multistage probability sampling for timber volume, using manual interpretation results derived from sample aerial photography and a limited amount of field data. This planned work not only capitalizes on the integration of manual and automatic data analysis techniques but also permits cost-effectiveness comparisons to be made between this computerized technique and conventional techniques used by the U.S. Forest Service to estimate timber volume.

4.3.1.2 Snow Surveys

A twofold research effort is proposed for this next reporting period with respect to snow surveys within the Feather River Watershed region. First, work will continue which is designed to document that areal estimates of snow cover can be made accurately, quickly and inexpensively using ERTS-1 data. The interpretation key and analysis techniques developed during this last reporting period with the aid of U-2 photography will be applied to ERTS-1 imagery taken during the 1972-73 melt season. Second, an effort will be made to integrate estimates of snow cover into working stream flow forecasting models. An example model is discussed below and was developed by Leaf and Haeffner.*

*Leaf, D. F. and A. D. Haeffner. 1971. A Model for Updating Stream Flow Forecasts Based on Areal Snow Cover and a Precipitation Index. Presented at the Western Snow Conference, Billings, Montana, April 20-22, 1971.

This model is based on an estimate of areal snow cover and a precipitation index. Three types of information are needed in order to develop the forecast curves, which are used for predicting residual volume. These are (1) aerial (or satellite) images taken during the melt season, (2) precipitation data, and (3) runoff data for the watershed in question.

Three steps need to be taken in developing runoff forecast curves. The first is to develop a snowpack depletion-runoff curve. The relationship between snowpack depletion and runoff is fairly constant from year to year for any particular watershed, and thus, only a few years of data are needed to devise the curve (see Figure 4.17).

By use of the "observed" runoff information contained in Figure 4.17 a graph showing snow cover depletion as a function of residual flow can be derived. The family of curves shown in Figure 4.18 accounts for both "high" and "low" snow years. "High" and "low" snow years are a function of the initial amount of snowpack according to Leaf and Haeffner.

Since the terms "high" and "low" are subjective and open for debate as to how much snow they represent, they must be quantified. This is done by using a precipitation index. The graph which results is shown in Figure 4.19. In order to calculate precipitation indices the average annual precipitation for the watershed in question must be known. Once this is known, index weight factors can be calculated. Index weight factors are simply the ratio between the precipitation for a specific time period and the total average annual precipitation.

By using the equation:

$$I_p = 100\ [W_m i_m + W_a i_a + W_m i_m + W_j i_j]$$

SPANISH CREEK WATERSHED

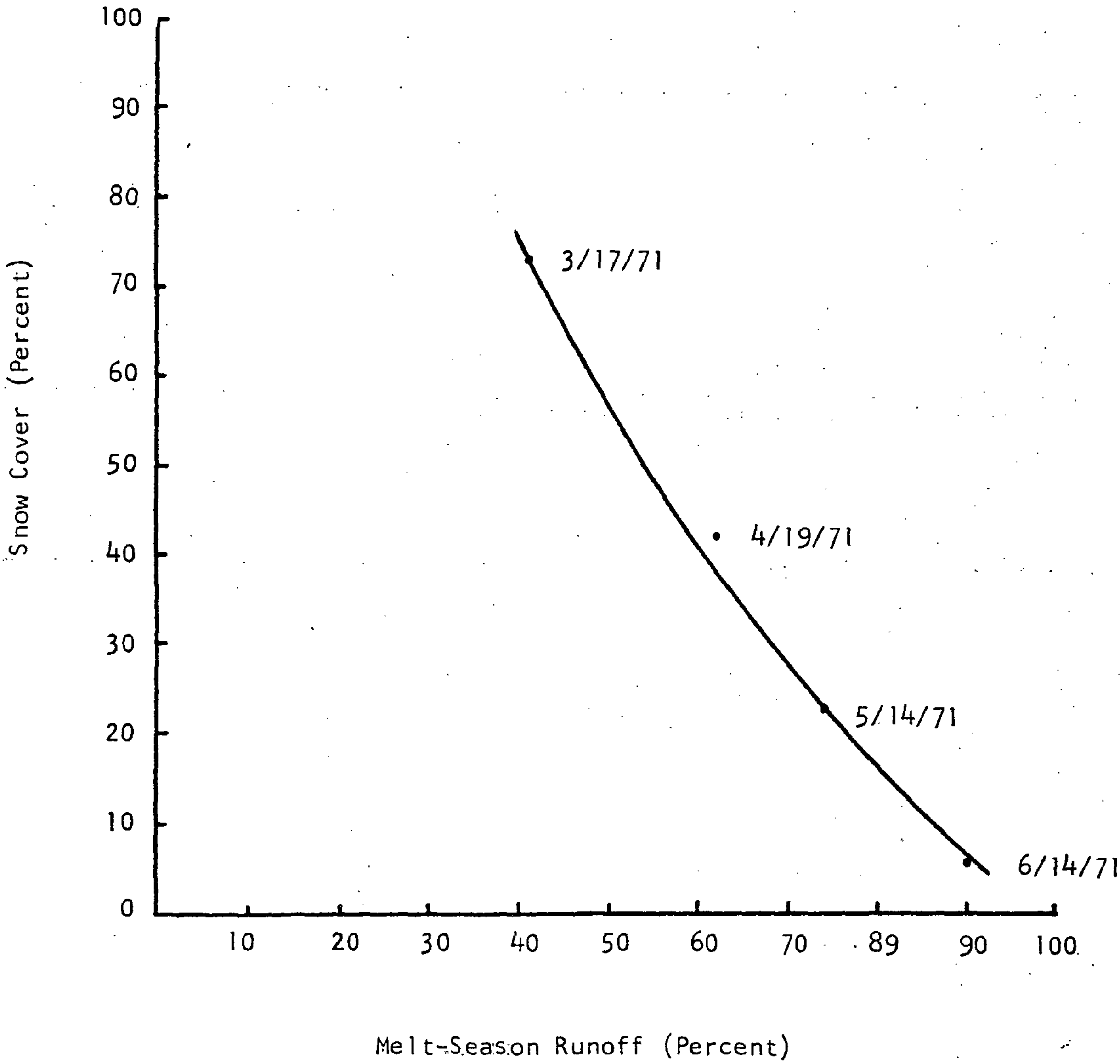


Figure 4.17. Snowcover depletion as a function of accumulated runoff, 1971. The curve is based on only one year's data. Accuracy should improve when it becomes possible to base such a curve on several years' data.

SPANISH CREEK WATERSHED

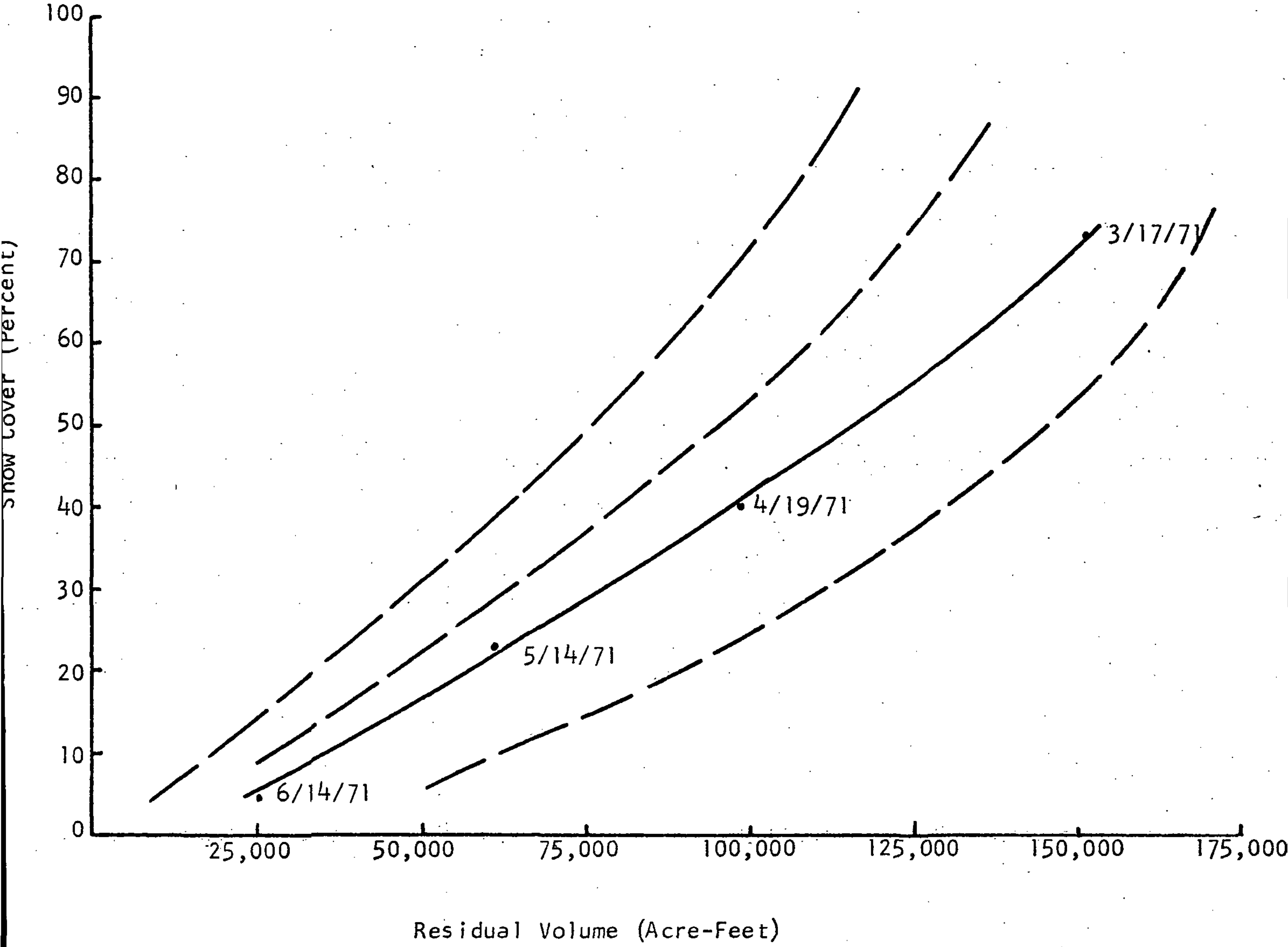


Figure 4.18. Snow cover depletion as a function of residual flow. The solid curve is based on valid 1971 data. The possible locations of additional curves, had data been available, are represented by the dashed lines.

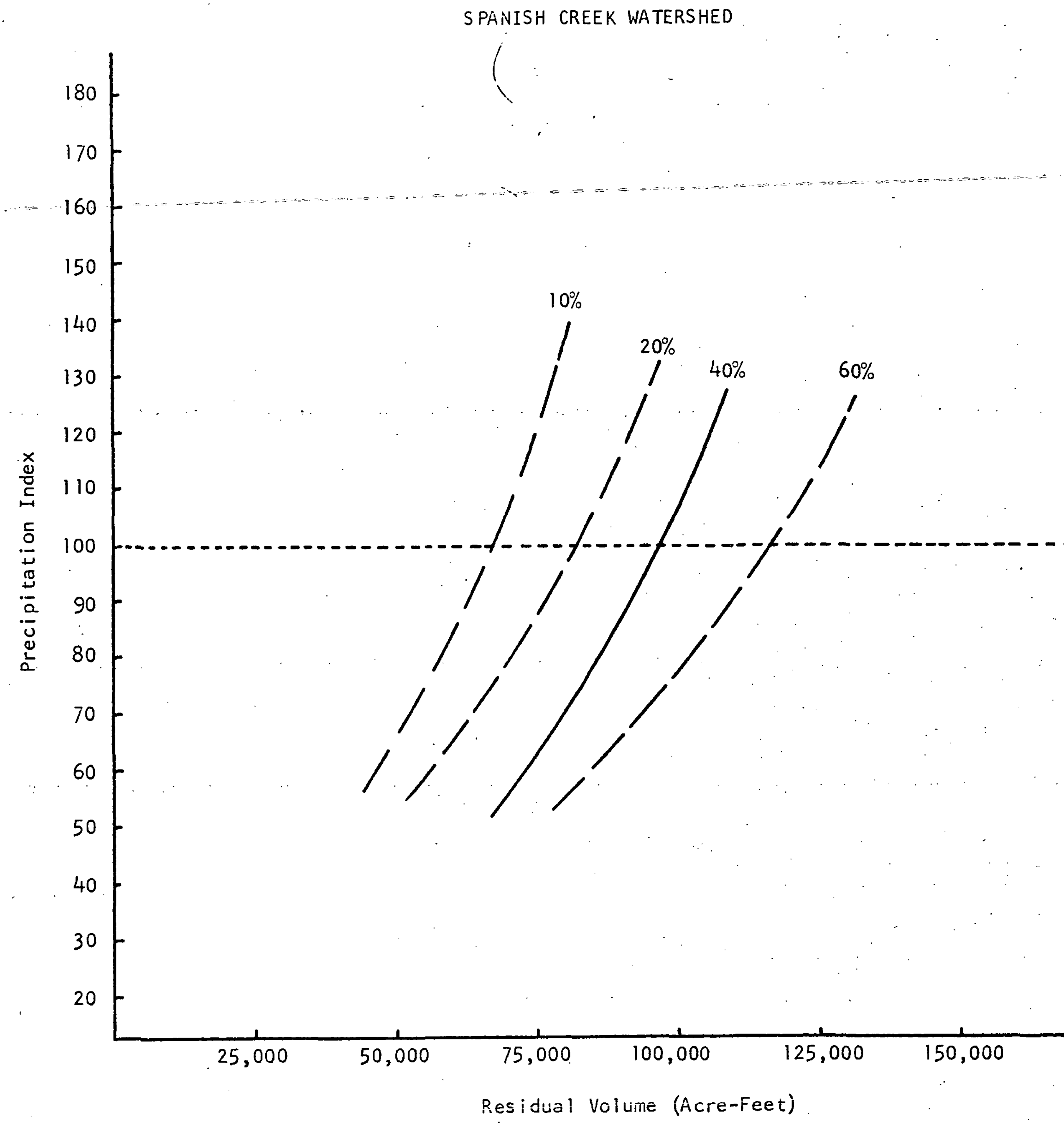


Figure 4.19. Snow cover precipitation index forecast curves. The solid line represents the actual location of the 40 percent curve, based on two observations of approximately 40 percent snow cover. The possible locations of additional snow cover percent curves are represented by the dashed lines.

where

I_p is the weighted precipitation index

W_m is the weight factor for seasonal snow accumulation through March 30

i_m is the snow accumulation index through March 30 (ratio between observed value for the year in which forecast is being made and average value)

W_a is weight factor for April

W_m is weight factor for May

W_j is weight factor for June

i_a is the precipitation for April

i_m is the precipitation for May

i_j is the precipitation for June,

one is able to calculate the precipitation index and then, with knowledge of snow cover percent, determine the forecasted residual volume for any particular year. Table 4.12 illustrates how a precipitation index is calculated.

The precipitation index equation allows for adjustments as the melt season gets under way. For example, the precipitation index calculated on March 30 can be adjusted to reflect abnormal precipitation during the month of April by changing the weight factor (W_a). Leaf and Haeffner have shown that this adjustment process greatly increases the accuracy of the forecast.

The validity of the above forecasting model has been shown, using large-scale (1:6,000) photographs on small watersheds ($<$2000 acres).

TABLE 4.12. EXAMPLE OF PROCEDURE FOLLOWED FOR DERIVING PRECIPITATION INDICES

Precipitation Summary 1967-72

Watershed	Peak (March 30)	April	May	June	Total
Spanish Creek	27.43	3.46	1.44	1.29	33.62

Index Weight Factors

Spanish Creek	.82	.11	.04	.03	1.00

Assume for year 1973, precipitation for March 30 = 20.00"

$$I_p = 100\left[\frac{20.0}{27.43}(.82) + 1.0(.11) + 1.0(.04) + 1.0(.03)\right] \quad 77 = \text{precipitation ind}$$

It is anticipated that the forecasting model can give accurate forecasts on larger watershed and when using ERTS-1 imagery. Future research will involve using ERTS-1 imagery to acquire snow-cover percentages in order to construct the forecasting curves for the entire Feather River Watershed.

4.3.2 Analysis Within the Northern Coastal Zone

The Forestry Remote Sensing Laboratory (FRSL) will continue to orient its research towards determining what remote sensing system is operationally feasible for use by environmental planners at the regional level within the North Coast Test Site of California.

Increased interaction with planners is scheduled to include the planning of each county within the test area as well as other regional agencies (e.g., ABAG) and State agencies (e.g., California Coastal Zone Commission). It is hoped that through these interactions with the users, an adequate roster of planning needs and priorities can be more or less finalized. In addition, the quantification of what can be provided by the remote sensing tool in terms of accuracies and costs is expected to progress significantly.

Our determination of the amount of information of certain types which can be interpreted from ERTS-1 and high altitude photography is far from complete. Analysis plans call for additional interpreters to delineate and classify ERTS-1 imagery from the July 27 pass. This procedure will be repeated for other ERTS-1 passes where usable (good quality) imagery is available. Further emphasis will be given to determining what information can be extracted from the black-and-white MSS bands. It was apparent during this most recent phase of study

that the mapping on individual bands was inferior to mapping on the color composite imagery but further analysis is required to determine what specialized mapping tasks can be accomplished through analysis of individual black-and-white MSS bands.

During the next reporting period, emphasis will be placed upon developing techniques for detecting features which have undergone change during the time interval between cloud-free ERTS-1 passes. Attention will be devoted to the recording of all land parameters which can be monitored and which signify important changes in the environment. Documentation will also be made of those features which can be accurately detected, delineated, classified, and identified by virtue of their changing appearance during specific seasons.

All analysis procedures being applied in the southern intensive study area will be, or are being, applied in a northern study area where resource types and land use patterns are significantly different. Moreover, a generalized land use map for the entire north coast of California will be prepared once cloud-free imagery (ERTS-1) of the entire test site area is available. The purpose of making this map is to determine if the level of information mapped over a large regional area is of value ot regional planners. Finally, automated interpretation techniques will be applied to selected areas within the test site. Thus, the degree to which classification can be achieved of important land use categories by means of computer analysis will be evaluated.

N74-14090

Chapter 5

RIVER MEANDER STUDIES

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5.1 INTRODUCTION

We are investigating the possibility that significant information on stream flow rates can be obtained from aerial and satellite imagery of river meander patterns by seeking a correlation between the meander and discharge spectra of rivers. Such a correlation could provide the basis for a simple and inexpensive technique for remote sensing of the water resources of large geographical areas, eliminating the need for much hydrologic recording. The investigation of the nature of the meander and discharge spectra and their inter-relationship can also contribute to a more fundamental understanding of the processes of both river meander formation and drainage of large basins. This paper is a progress report on this investigation.

A large number of correlations between some average meander wavelength and some characteristic discharge have been proposed (see for example Jefferson, 1902; Inglis, 1949; Leopold and Wolman, 1957; Dury, 1965; Carlston, 1965; Schumm, 1971). These correlations clearly suggest that there is a relationship between meander wavelength and discharge but they fail to agree on its quantitative form. We believe that this disagreement may result primarily from the oversimplification

inherent in using a single meander wavelength and a single discharge to characterize the river rather than using the complete spectra of wavelengths and discharges.

Speight (1965, 1967) appreciated that the entire oscillatory pattern of a river must be important in characterizing its meandering and presented power spectra of the auto-correlations of the directions of flow measured at equally spaced points on the talwegs of several Australasian rivers. These meander power spectra showed structure which he interpreted as an indication that several characteristic length scales may be required to quantitatively describe a meander pattern. The idea of using a spectral analysis of the reach of a river as the basis of a correlation rather than a subjective estimate of an assumed single length scale is a necessary generalization in describing the connection between a river's meander pattern and its discharge. However, he retained the idea that a single discharge could be correlated with the multiple length scales. Just as there is an essential difficulty in attempting to characterize a meander pattern by a single length scale, there is a fundamental problem in trying to choose the dominant discharge, i.e. that discharge most effective in establishing the system of meanders. We propose that the further generalization of the correlation to include the time-behavior of the discharge may bring an order to the relationship between the total meander pattern and the complete record of the discharge. Hopefully this more general correlation will be sufficiently reliable to quantitatively assess a river's flowrate from a spectrum of its meanders, thus making the knowledge of

a region's water resources accessible from aerial or satellite imagery of the area. As a basis for this study we have developed a fully automated system for obtaining both the discharge and meander wavelength spectra. Discharge spectra (probability of discharge per unit discharge vs. discharge) are constructed from historical records of daily stream discharge. Generation of meander power spectra involves three elements: digitization by photoelectric optical tracking of stream banks on each frame of photographic or television imagery; collation and matching of successive frames into a single data record for each stream; and a Fourier transform analysis of the data. This system has been developed to facilitate the analysis of the large number of rivers required to assure the statistical reliability of the correlation.

Rivers have been selected on the basis of availability of both historical hydrologic data and aerial or satellite imagery, and on the absence of obvious geologic control of the river meander pattern. The statistical reliability of any correlation between the meander spectrum and the discharge frequency distribution depends upon the study of a large number of rivers whose discharges cover as great a range as possible. We have obtained aerial photographs (both infrared and panchromatic) of rivers from the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture, Department of Water Resources of the California State Resources Agency, the Topographical Division of the U.S. Geological Survey, and the Cartographic and Audiovisual Records Division of the National Archives and Records Service. Infrared satellite imagery from ERTS-1 has been provided by the NASA

Data Processing Facility at Goddard Space Flight Center. Historical streamflow data in machine readable format have been obtained from the Water Resources Division of the U.S. Department of the Interior.

From the imagery of a selected river reach, we determine the positions of the curve with respect to a cartesian coordinate system. This description of the river's course is transformed to a (θ,s) representation, where θ measures the angle that the curve makes with a reference direction as a function of distance travelled along the curve s. The (θ,s) description is preferred since the meander pattern of a river may be represented by a multivalued function of position in a cartesian representation. The meander power spectrum which we calculate is the power spectral density of $\theta(s)$.

5.2 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

5.2.1 Analysis Techniques

5.2.1.1 Digitization

The digitization of river meander patterns from aerial and satellite imagery is most accurately and economically accomplished through photoelectric optical scanning. We have developed a program for digitizing river meanders, using commercially available machines employing this technique. An important condition on the digitization procedure is that data points be located at equal increments of distance along the meander curve. This condition follows from the fact that local meander direction, θ, is a function of distance along the meander and the algorithm used for constructing the power spectrum requires that we know this quantity at equal increments of distance.

The essence of the digitization procedure is as follows (see also Figure 5.1). The initial point on the meander pattern is found by scanning along a horizontal or vertical line and measuring the optical density profile along the scan (line AB in Figure 5.1). The river bank, i.e., the point digitized, is defined as the location of the point of maximum gradient in the density profile (point 1). The second point is determined by an iterative process starting with a scan (line CD) parallel to the initial scan but displaced by a distance, s, from point 1. The first estimate of this point (2') is determined in the same manner as above. The distance between points 1 and 2' is then calculated and if it is not equal to the required spacing, s, plus or minus some small Δ, another scan (line SF) is made along a line perpendicular to that line connecting points 1 and 2' at a distance s from point 1. Point 2'' is then determined along this scan. If the distance between it and point 1 is still not within $s \pm \Delta$, the iterative process is repeated until convergence is obtained. Once point 2 is located, the search for point 3 begins along a scan line (GH) perpendicular to the line connecting points 1 and 2 at a distance s from point 2. In this manner the machine proceeds along the meander curve digitizing points at equal distance increments along the curve.

As is generally the case, the imagery of the river consists of a number of overlapping frames, thus this digitization procedure is repeated for each frame. The data for adjacent frames must then be matched to give a continuous digitized record of the meander pattern. Because of the large overlap between frames (roughly one-third of the data on the

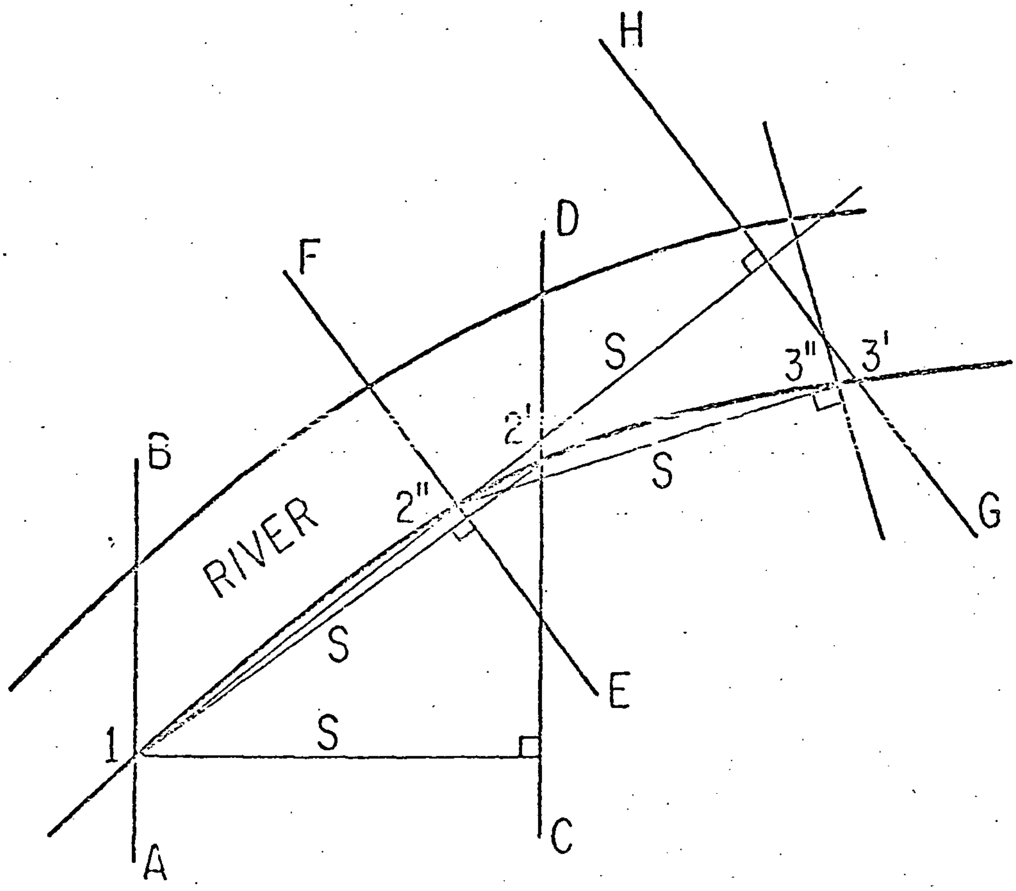

Figure 5.1. Digitization procedure for determining the position of a river at equally spaced points along its course.

end of each frame overlaps with the data on the beginning of the next frame) the data sets can be uniquely matched for congruency in the overlap region. We have developed a computer program which finds the appropriate coordinate transformation, i.e., includes both translation and rotation of one frame with respect to the other. This is accomplished by considering a length of river half the length of the overlap region on one frame and effectively sliding this portion of the data along the overlap portion of the adjacent frame, finding that transformation within the overlap region which minimizes the sum of the squares of the distances between matched points. Once the appropriate coordinate transformation is determined all of the data points on the second frame are transformed to the coordinate system of the first frame. The process is then repeated to match successive frames until the entire record is transformed into a single coordinate system.

5.2.1.2 River Meander Power Spectra

The digitization and matching procedures described above produce a set of data points (x,y coordinates) which are equally spaced along the course of the river. A power spectral analysis of the river cannot be made directly from the x versus y data since the river may double back upon itself making x a double valued function of y. An equivalent representation of the river, which is single valued and thus amenable to power spectral analysis is its local direction θ, as a function of the distance, s, along the river's course. The power spectral density (deg^2 10^3 foot) for the direction θ is computed using standard techniques for determining the auto-correlation function, smoothing, and

taking the Fourier transform (e.g., J.S. Bendat and A.G. Piersol, 1966).

5.2.1.3 Discharge Spectra

The discharge spectrum or frequency distribution of a river is the probability per unit discharge that its discharge, or flow rate, Q lies within the interval ΔQ at Q. The integral of this distribution over discharge is the flow duration curve commonly used in hydrologic studies (see, for example, Chow, 1964). From an historical discharge record of length T, the frequency distribution which we calculate is $\frac{1}{T} \cdot \frac{\Delta t}{\Delta Q}$ where Δt is the portion of the time the discharge lies within ΔQ at Q.

5.2.2 Data

5.2.2.1 Discharge Spectra

From historical records of daily river discharge, we have constructed the frequency distributions from the fraction of time the discharge lies within a prescribed interval per unit interval. A remarkable property of most of these discharge frequency distributions is their nearly linear character on log-log plots for values of discharge larger than the mode (Schubert and Lingenfelter, 1973). Several examples of this are shown in Figure 5.2. The daily discharge data on which each distribution was based extends over the indicated time interval for the particular gauging station identified by number according to the convention adopted by the U.S.G.S. (1964). The slopes of the linear portions of these distributions vary from river to river and even from station to station on the same river over the range from less than -1 to -5. Flow duration curves have previously been interpreted as representing a random process described, for example, by a log-normal distribution

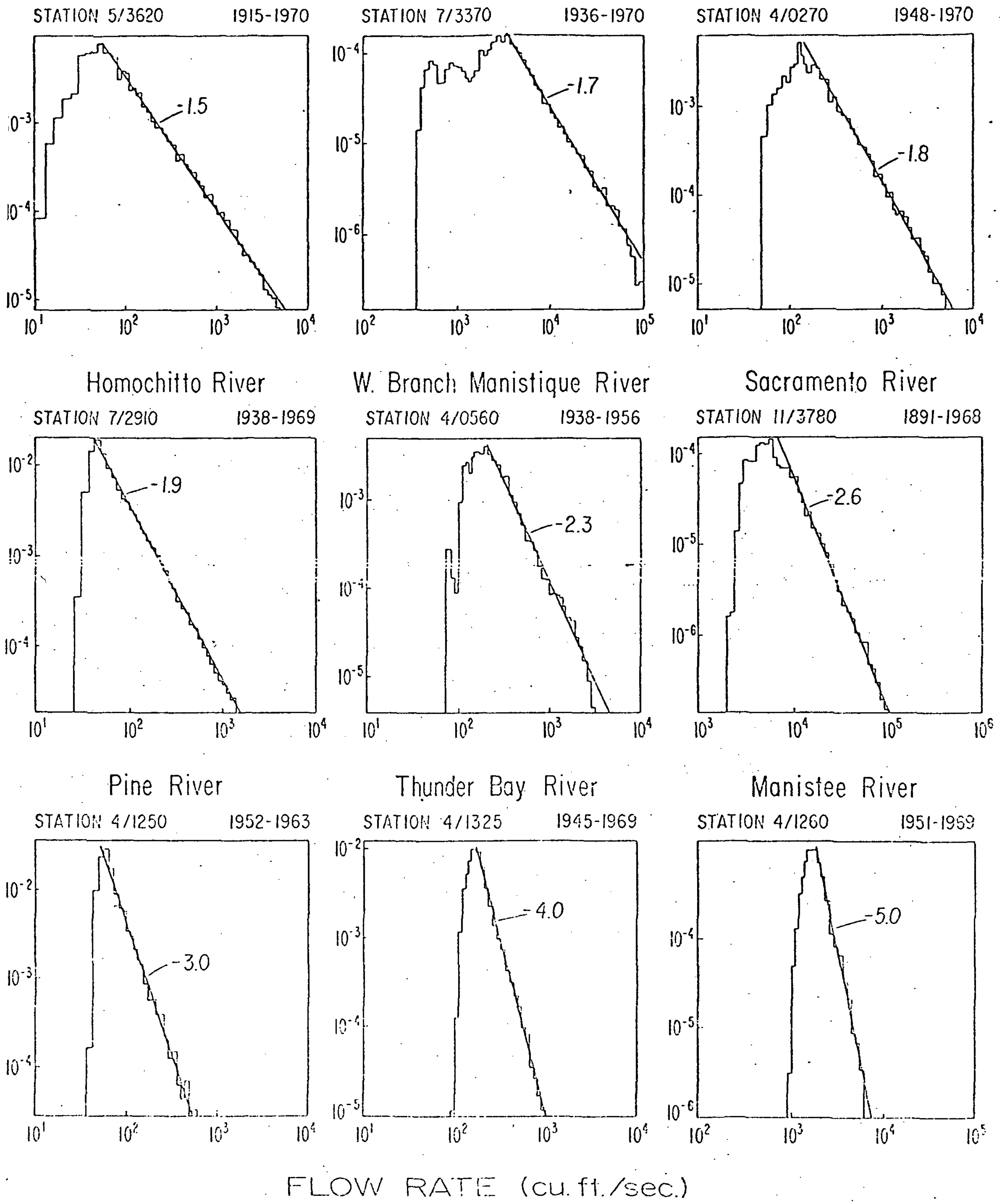

Figure 5.2. Log-log representations of discharge frequency distributions (probability per unit discharge that discharge Q lies within ΔQ at Q) for a number of rivers identified by name and U.S.G.S. gauging station number based on daily discharge data over the period noted. The straight lines with slopes indicated represent best fits to the linear parts of the distributions.

(Chow, 1964; Leopold et al., 1964). Our results, however, show that such an interpretation is not appropriate for a large number of rivers, since it is inconsistent with the clearly linear character of the log-log frequency distribution plots. Instead, we suggest that the distribution for discharges greater than the mode must be essentially deterministic in nature, reflecting the decay phase of the flood hydrograph. We have not found any previous suggestion of a direct relationship between the form of the flow duration curve and the flood hydrograph.

If s is the slope of the log-log frequency distribution, then

$$\frac{dt}{dQ} \propto Q^s \quad . \tag{1}$$

Integrating equation (1) we find

$$Q \propto t^{\frac{1}{s+1}} \quad . \tag{2}$$

Since the observed values of s lie between about -1.5 and -5 the exponent $\frac{1}{s+1}$ would range from about -2.0 to -0.25. We suggest that equation (2) represents the decay phase of the flood hydrograph, where t is measured from a time t_0 near the flood peak. The time t_0 can be uniquely determined from any two discharge measurements Q_1 , Q_2 at times t_1 , t_2 during the flood recession by

$$t_0 = \left\{t_2\left(\frac{Q_1}{Q_2}\right)^{s+1} - t_1\right\} / \left\{\left(\frac{Q_1}{Q_2}\right)^{s+1} - 1\right\} \quad . \tag{3}$$

The inverse power law dependence of the discharge on time, which we find here, differs from the superposition of several exponential decay curves, which have previously been used (Chow, 1964) to empirically

fit the flood recession.

To test our suggestion that the linear nature of many of the log-log frequency distributions represents the recession portion of the flood hydrograph, we have compared the time dependence of the discharge predicted by equations (2) and (3) with the measured decay of discharge following individual flood peaks on the various rivers studied. We find that the predicted decay at each station does indeed describe the measured discharge following all flood peaks at that station. A typical example of the agreement between predicted and measured flood recession is shown in Figure 5.3 for the Sacramento River near Red Bluff, California, in 1936. As can be seen, the curves of the theoretical flood decay are an excellent fit to the data points which indicate the measured values of the daily discharge. The theoretical curves are based on a value of s equal to -2.6 (see Figure 5.2) and values of t_0 equal to 16 January, 22 February and 4 April for the respective floods shown in Figure 5.3. At this station on the Sacramento River floods decay according to the rule $t^{-0.625}$, which allows the recession to be determined for as long as a month following the flood peak. From the hydrograph of Figure 5.3 it can be seen that the deterministic flood decay extends down to discharges of about 10^4 c.f.s. at this station. Below this discharge level the flow rate variations appear to be stochastic in nature. This also is consistent with the fact that the linear relationship in the log-log frequency distribution (Figure 5.2) ceases at discharges below about 10^4 c.f.s. at this station. Below this discharge level the flow rate variations appear to be stochastic in nature.

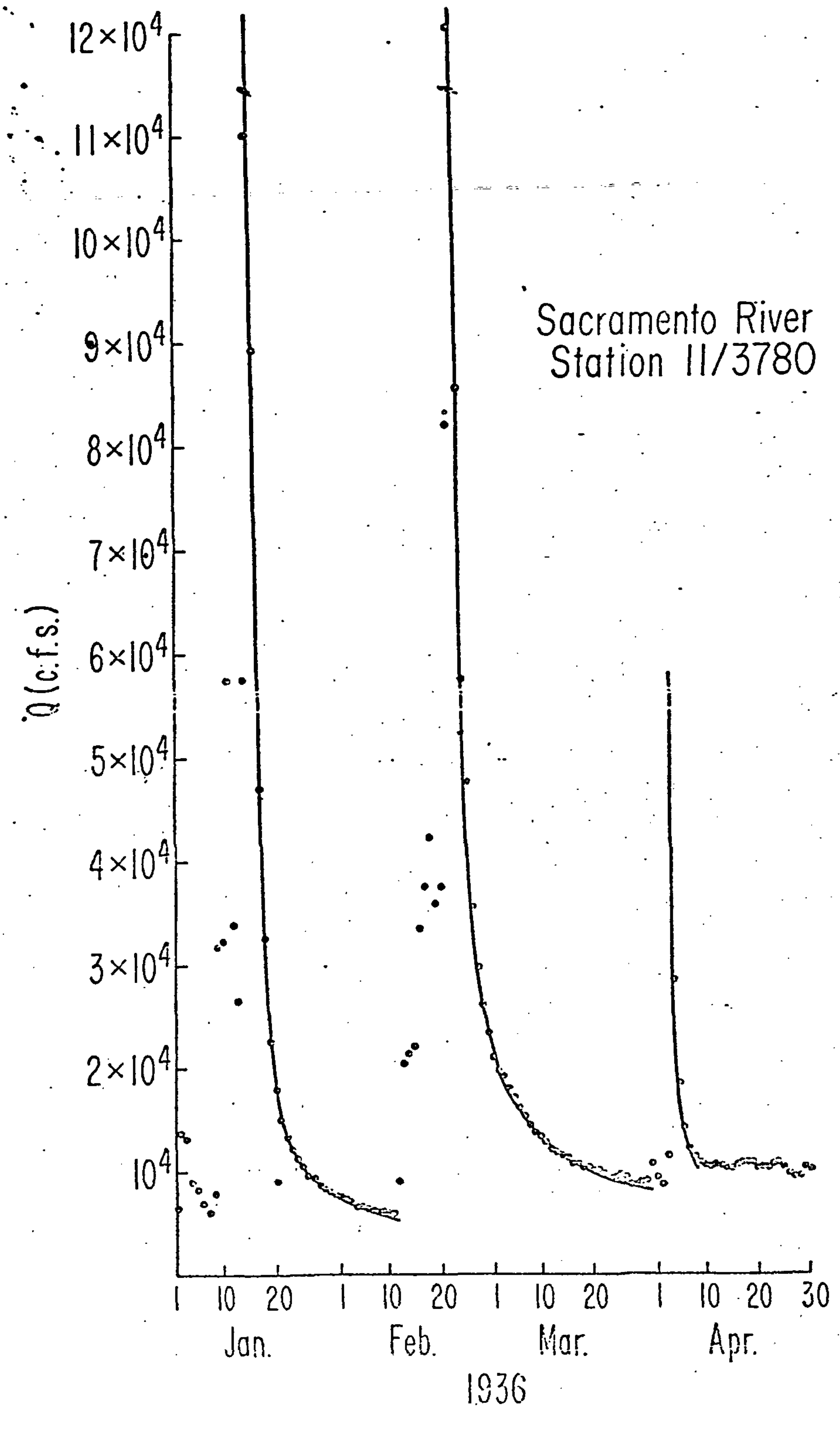

Figure 5.3. Typical daily discharge data (circles) showing the recessions of three floods on the Sacramento River near Red Bluff in 1936. The theoretical curves of the form $t^{1/(s+1)}$ are based on the $s = -2.6$ power law dependence of the discharge frequency distribution on discharge at this station shown in Figure 5.2. The good agreement between the theoretical curves and data shows that the flood recessions follow an inverse power law dependence on time which in turn is reflected in the power law dependence of the discharge frequency distribution.

This also is consistent with the fact that the linear relationship in the log-log frequency distribution (Figure 5.2) ceases at discharges below about 10^4 c.f.s. at this station.

Even more complex discharge spectra, such as those in Figure 5.4, still reflect a power law dependence of the flood recession in their linear character at the highest flow rates. The floods at these two stations on the Otter and South Fourche La Fave Rivers do indeed decay according to $t^{-1.25}$ and t^{-2} dependences, as reflected by the slopes of -1.8 and -1.5 on the respective discharge spectra. The difference between the spectra shown in Figure 5.4 and those of Figure 5.2 can be easily understood in terms of a discharge spectrum that is the sum of two components: a gaussian distribution reflecting the low stochastic level of flows and a linear distribution reflecting the power law time dependence of the flood recession. Thus on the Otter River, the linear dependence of the discharge spectrum does not extend down to the modal flow rate because the flow is at the stochastic level a relatively large fraction of the time, dominating the spectrum even at flow rates somewhat above the mode. On the South Fourche La Fave River on the other hand, the stochastic level is at a lower discharge and the recession of one flood is generally truncated by the onset of another flood before the stochastic level is reached with the result that the linear character of the discharge spectrum is broken well above the stochastic mode. The relative importance of the stochastic and flood components may reflect differences in the relative contribution of runoff and ground water to the overall stream flow.

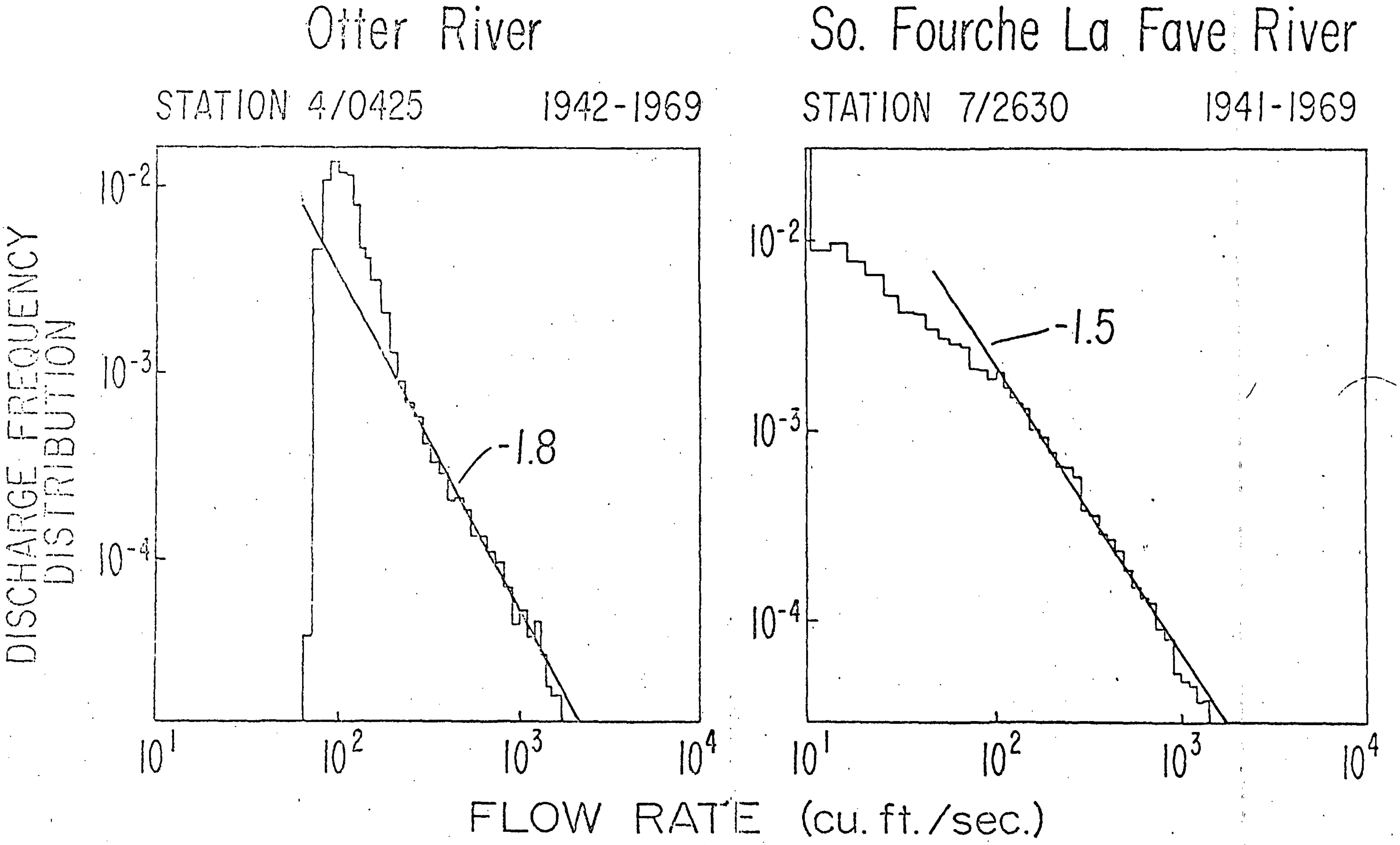

Figure 5.4. More complex discharge frequency distributions, which still show a linear character at large flow rates reflecting a power law dependence in their flood recession.

Thus we see that apparently on most rivers, floods decay with an inverse power law dependence on time. The exponent of this dependence varies from river to river and also from station to station along the same river. Examples of the latter variation can be seen in Figure 5.5 which shows discharge spectra at two gauging stations on each of three rivers. For the Red River, the slope decreases from -1.7 at the upstream station to -1.4 at the downstream one, for the Homochitto River the slope is approximately the same at both stations and for the Pine River the slope increases from -3.0 at the upstream station to -4.1 at the downstream one. We see from these examples that there is no general trend in the variation of the slope of the discharge spectrum with position along a river.

Despite the complex interaction of the large number of factors which undoubtedly affect the flow at any point on a stream, the resultant time dependence for most rivers can thus be described by a single parameter, which can be uniquely determined from long-term records of the discharge. We note that an inverse power law dependence of the flow rate on time is characteristic of diffusive processes, suggesting a direction for future hydrologic modeling of the flood recession.

Our primary purpose in this study, however, is to seek a correlation between discharge spectra and river meander power spectra. To do this we intend to first consider rivers whose discharge spectra are sharply peaked such that only a narrow range of discharge can be effective in producing the meander pattern. Examples of such discharge functions can be seen in Figure 5.6. If we can find a correlation for these

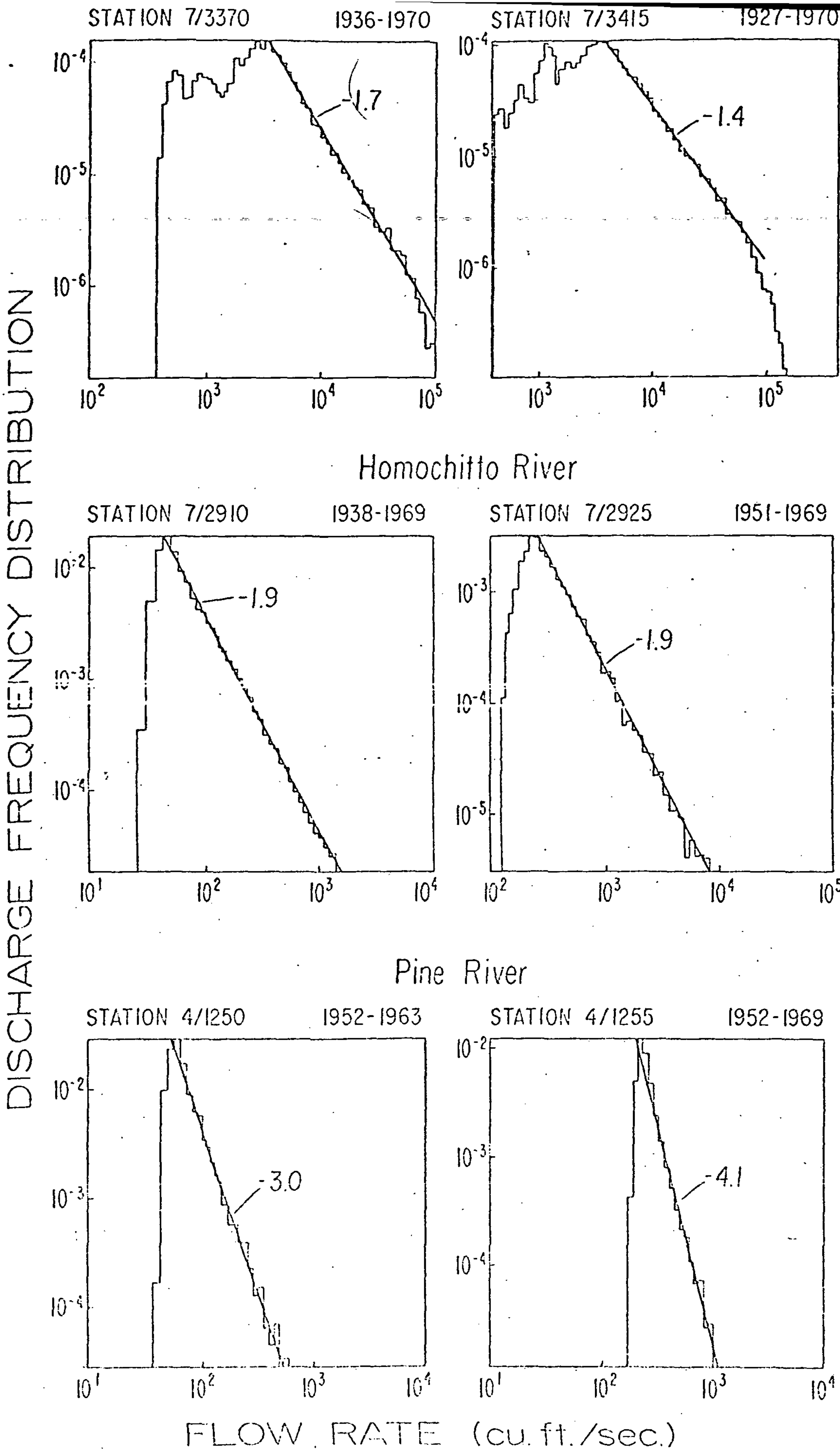

Figure 5.5. Examples of variations of the power law exponent of the discharge frequency distribution with position along a river.

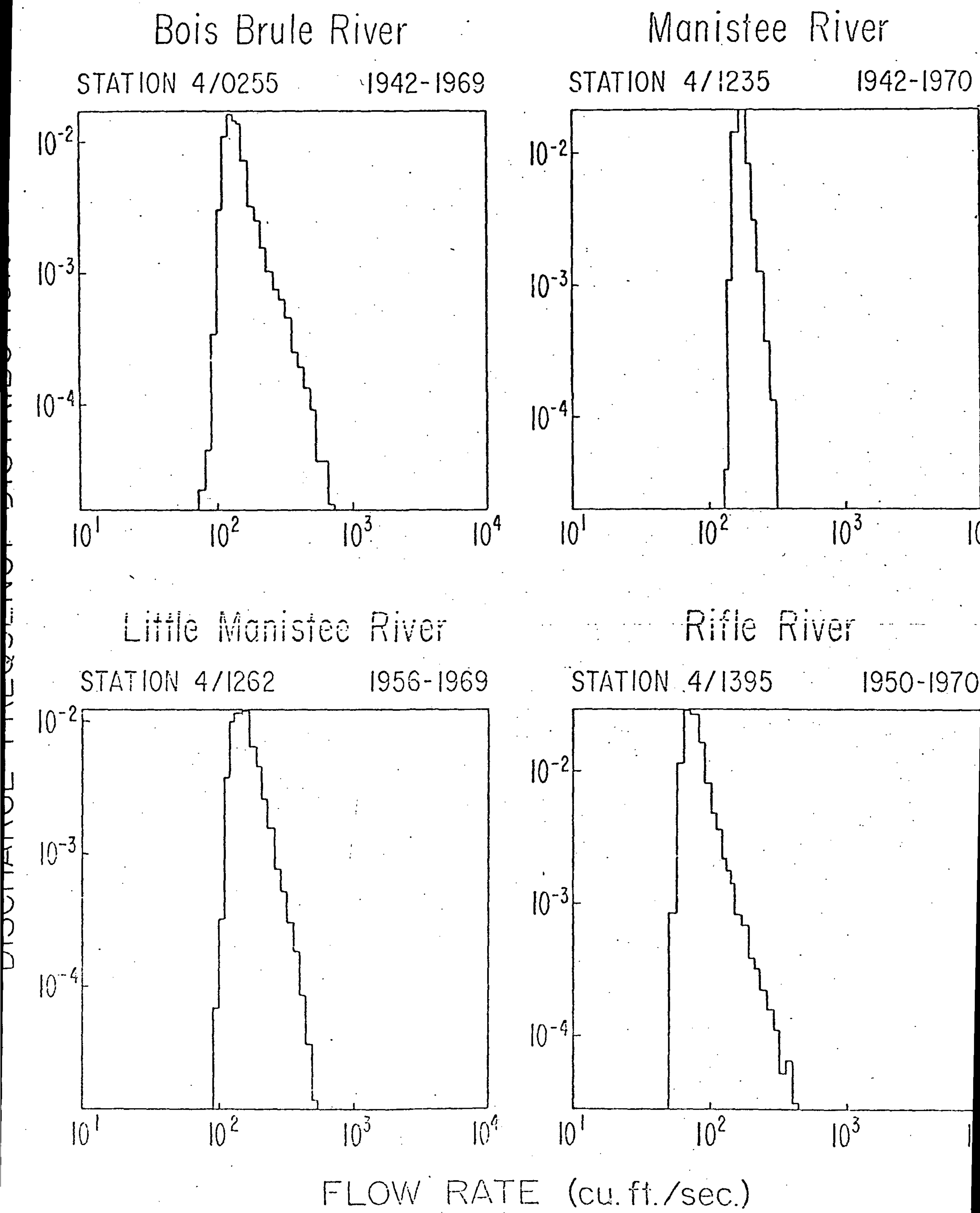

Figure 5.6. Examples of sharply peaked discharge spectra.

relatively simple discharge spectra, then, using the principle of superposition, for example, we may be able to extend the correlation to rivers with broader and more complex discharge spectra.

5.2.2.2 Meander Spectra

Using the techniques and imagery already discussed, we have begun constructing meander power spectra of the local river direction as a function of distance along its course. These spectra are plots of power spectral density (deg^2 10^3 feet) versus wave number (per 10^3 feet). The range of wave number is limited at the high end (short wavelength) by the interval between data points and at the low end (long wavelength) by the length of the reach Fourier analyzed and the number of degrees of freedom. The maximum wave number is given by the Nyquist criterion to be $N/2\ell$ where N is the number of data points and ℓ is the length of the reach. The minimum wave number at which spectral information is obtained is $N/2\ell m$ where m is the number of spectral estimates, or alternatively $n/4\ell$ where $n = 2N/m$ is the number of degrees of freedom, a measure of the uncertainty in the power spectral density.

Most of the meander spectra which we have constructed so far are rather simple, broad spectra having significant power over a wave number range of more than a decade. Several examples of these spectra are shown in Figure 5.7, together with scaled traces of the meander patterns which have been spectrally analyzed. The error bar on each spectrum indicates the 80 percent confidence interval for the power spectral density determined from the number of degrees of freedom (Blackman and Tukey, 1958). The length of the reach ℓ, the number of data points,

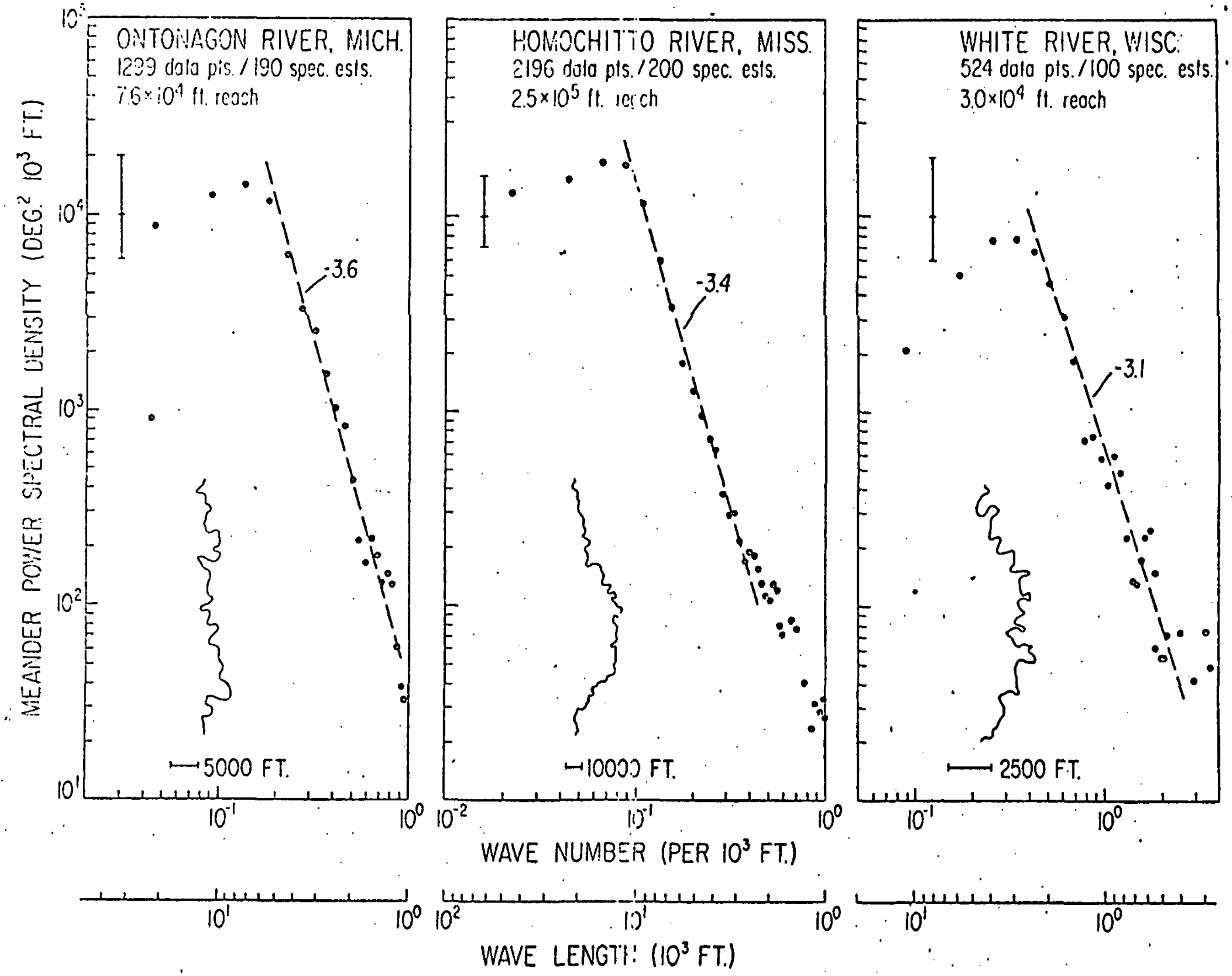

Figure 5.7. Power spectral density (deg^2 10^3 ft.) versus wave number (per 10^3ft.) and wave lenth (10^3 ft.) for three river reaches having rather simple, broad spectra. Power-law dependent segments of the spectra are approximately fitted by dashed lines with slopes indicated. A scaled trace of the meander pattern of each reach is also shown; the length of the reach, the number of data points, and the number of spectral estimates are given and the error bars indicate the 80 percent confidence interval for the power spectral density estimate.

N, and the number of spectral estimates m, are also indicated. Only that portion of each spectrum showing power significantly above the noise level of around 10^1 deg^2 10^3 feet has been plotted.

At intermediate wave numbers each of these spectra have an apparent power-law dependence of the spectral density on wave number, as shown by the dashed-line preliminary fit to the spectral estimates. The exponent of the power law is given by the indicated slope which is probably accurate to within ±20 percent. At lower wave numbers the spectrum flattens, suggesting a broad peak at a power density two to three orders of magnitude above the noise level. The wave numbers at which the power law dependence breaks to flatter dependence on the Ontonagon, Homochitto and White rivers correspond to wave lengths of 5×10^3, 10^4 and 2.5×10^3 feet, respectively, and reflect recognizable scales in the meander patterns of each river reach shown in the figure. At high wave numbers the power law dependence is truncated at the relatively constant level of the noise which extends up to the Nyquist limit on the wave number. Though there are small scale fluctuations about the general spectral structure outlined above, they are not significant within even the 80 percent confidence interval.

Some streams, however, do show more complex structure as can be seen in Figure 5.8. Clearly the off-set structure shown in the spectrum of the Manistee River is significant within the 80 percent confidence interval. There is also a suggestion of similar structure in the spectra of the Bad and Bois Brule rivers, though not at the same level of confidence.

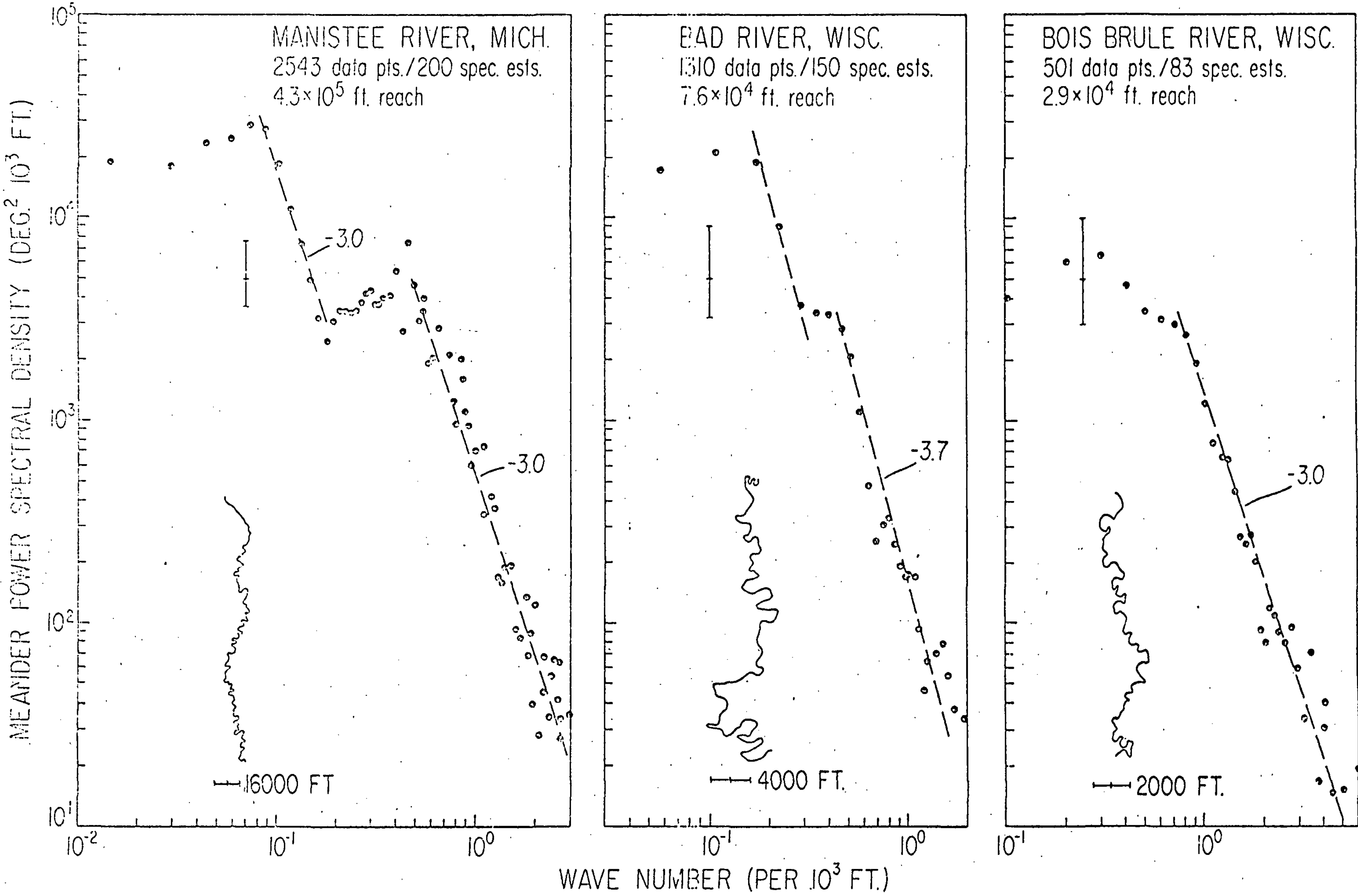

Figure 5.8. More complex meander power spectra showing two offset power-law dependent segments.

Thus the spectra which we have investigated so far can be described by one or more linear power-law segments of differing slopes and magnitude which break at characteristic wave numbers.

We have investigated the stationarity of meander power spectra by constructing spectra for a series of subreaches of the Manistee River to study the variation of its spectrum along the course of the stream. Figure 5.9 shows spectra for four consecutive subreaches, each of length 7.3×10^4 feet at the downstream end of the larger reach of the Manistee River shown in Figure 5.8. The subreaches may be recognized in the larger reach of the Manistee River by the traces of their meander patterns. As can be seen in Figure 5.9, the spectra of the four subreaches are quite similar; the slopes and magnitudes of the power-law segments of the spectra and the wave numbers of breaks in the spectra at 10^{-1} and 5×10^{-1} are the same in all four spectra to well within the 80 percent confidence interval. Thus these characteristic features of the power spectrum of the Manistee River are stationary over a length of at least 60 miles along its course. We have also constructed the power spectrum of a 7.3×10^4 feet subreach of the Manistee River located beyond the upstream end of the reach shown in Figure 5.8. This spectrum has only a single power-law dependent segment, breaking at a wave number of 1 and differing significantly from those shown in Figure 5.9. This difference is not surprising, however, in view of the fact that the median discharge in this upper subreach also differs by a factor of 5 from that in the lower subreaches.

In comparing our meander power spectra with those of earlier

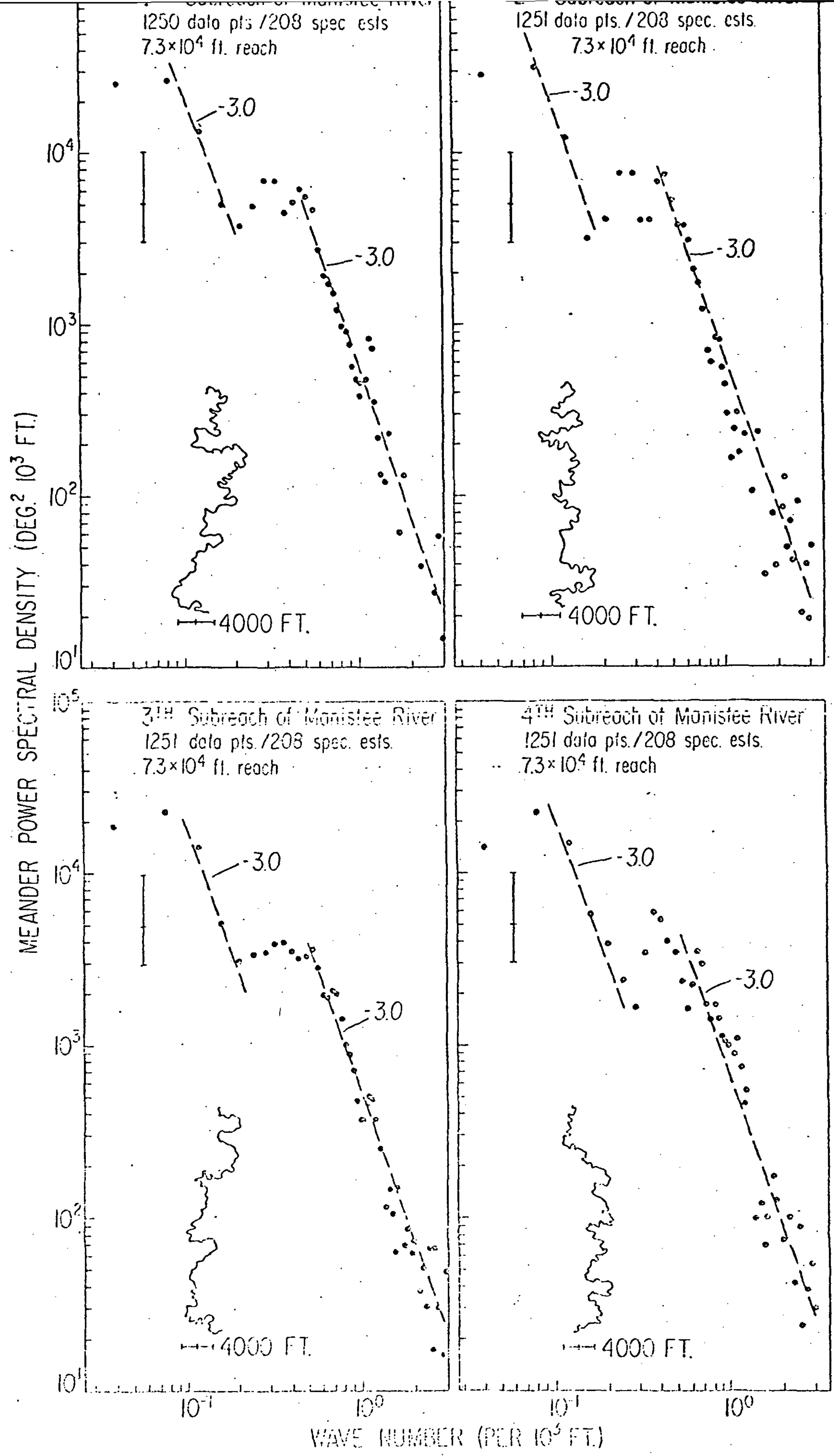

Figure 5.9. Stationarity of the offset structure in the power spectrum of the Manistee River shown by its persistence in the spectra of four separate reaches spanning a total length of sixty miles.

investigators (Speight, 1965, 1967; Toebes and Chang 1967) we note first that they used linear scales to plot the power spectral density estimates. Thus they did not observe the power law segments of meander spectra identified in this paper. Speight (1965, 1967) appears to have placed an unwarranted credence in the physical significance of a great many "spectral peaks", nearly all of which we would classify as random fluctuations on the power law portions of the spectra. In fact none of Speight's "peaks" were resolvable on the basis of the number of degrees of freedom which he used in his spectral analysis, but he attributed significance to them on the basis of some stationarity over the reach. On the other hand, Toebes and Chang (1967) have gone to the opposite extreme in suggesting that meander spectra are inherently nonstationary, reflecting only a randomness in the meander patterns. Neither of these investigators analyzed a large enough number of meander power spectra to justify their respective views.

Based on the rivers which we have studied so far (examples of which have been presented here) we believe that there is significant structure in a meander power spectrum, namely the slopes and mangitudes of the power law segments and the wave numbers at which breaks in these segments occur. It is these characteristic parameters of the meander spectra which we will attempt to correlate with such characteristics of the discharge spectra as the modal discharge and the exponent of the flood recession. Before this can be attempted, however, we must first generate a significantly large number of corresponding meander and discharge spectra on which to base a correlation.

5.3 FUTURE PROPOSED WORK

We plan to continue this basic study of river meander patterns and discharges and will attempt to correlate the discharge spectrum of a river with the river meander power spectrum determined from aerial and satellite imagery. Though we have not yet studied a large enough number of rivers to attempt a correlation between the discharge and meander spectra we have discovered some significant characteristics of both spectra. Discharge frequency spectra based on long term records of daily stream-flow are found to have an inverse power-law dependence on discharge. This is shown to reflect the short term decay of individual floods which are found to have an inverse power law dependence on time. Meander power spectra for a number of river reaches, digitized from aerial photography, also show significant structure, the power spectral density having an inverse power-law dependence on wave number over one or more portions of the spectrum with breaks in the spectrum at characteristic wave numbers. Now that space photography is becoming available we anticipate being able to use these same techniques for very large rivers such as the Mississippi and the Amazon having discharge rates in the order of several thousand cubic feet per second. Consequently, we will be able to apply our correlated analysis over a far more meaningful range of stream discharge rates and associated meander power spectra as we bring this work to a definitive conclusion.

5.4 REFERENCES

Bendat, J.S., and A.G. Pierol, 1966, Measurement and Analysis of Random Data, New York, John Wiley.

Blackman, R.B., and J.W. Tukey, 1958, The Measurement of Power Spectra, New York, Dover.

Carlston, C.W., 1965, The relation of free meander geometry to stream discharge and its geomorphic implications, Am. J. of Sci., 263, 864-885.

Chow, V.T., 1964, editor, Handbook of Applied Hydrology, A Compendium of Water-Resources Technology, New York, McGraw-Hill.

Dury, G.H., 1965, General theory of meandering valleys, U.S. Geological Survey Prof. Paper 452-C, 43 pp.

Inglis, C.C., 1949, The behavior and control of rivers and canals, Poona, India, Central Waterpower Irrig. Navigation Research Sta., Research Pub. 13, pt. 1, 298 pp.

Jefferson, M.S.W., 1902, Limiting width of meander belts, Nat. Geog. Mag., 13, 373-384.

Leopold, L.B., and Wolman, M.G., 1957, River channel patterns: braided, meandering, and straight, U.S. Geological Survey Prof. Paper 282-B, 85 pp.

Leopold, L.B., M.G. Wolman and J.P. Miller, 1964, Fluvial Processes in Geomorphology, Freeman, San Francisco, pp. 67-69.

Schubert, G., and R.E. Lingenfelter, 1973, Flood recession, Science (in press).

Schumm, S.A., 1971, Fluvial geomorphology: the historical perspective, in River Mechanics, H.W. Shen ed., Fort Collins, Colo., Shen.

Speight, J.G., 1965, Meander spectra of the Angabunga River, Journal of Hydrology, 3, 1-15.

Speight, J.G., 1967, Spectral analyses of meanders of some Australasian Rivers, in Landform Studies from Australia and New Guinea, pp. 48-63, J.N. Jennings and J.A. Mabbitt, editors.

Toebes, G.H., and T.P. Chang, 1967, Planform analysis of meandering rivers, International Association of Hydraulic Research Proceedings, Vol. 1, 362-369.

U.S. Geological Survey, 1964, Compilation of Records of Surface Waters of the United States, October 1950-September 1960, Parts 1-14, Geological Survey Water Supply Papers 1721-1738.

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Chapter 6

ASSESSMENT OF RESOURCES IN THE CENTRAL REGIONAL TEST SITE

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6.1 INTRODUCTION

The Geography Remote Sensing Unit (GRSU) on the Santa Barbara campus is responsible for the Central Regional Test Site (see Figure 6.1). Although some of the studies being conducted and reported on here are area specific, they are designed to have broad regional implications. The research focus of GRSU is an investigation of remote sensing applications that contribute to an understanding of processes and phenomena of resource significance in this test area.

Information is currently being extracted from Mission 164 and ERTS-simulation high flight imagery relative to: (1) population estimation; (2) the amount and distribution of cultivated land in Kern County, California; (3) construction of a vegetation map of the West Side of the San Joaquin Valley; (4) development of a standardized multi-functional data base for the Central Coastal Zone of the State of California; and, (5) an analysis of land use change in the Goleta Valley, Santa Barbara County, California.

The Central Regional Test Site is primarily composed of ten central California counties, with integrated study overlap areas along the coastal

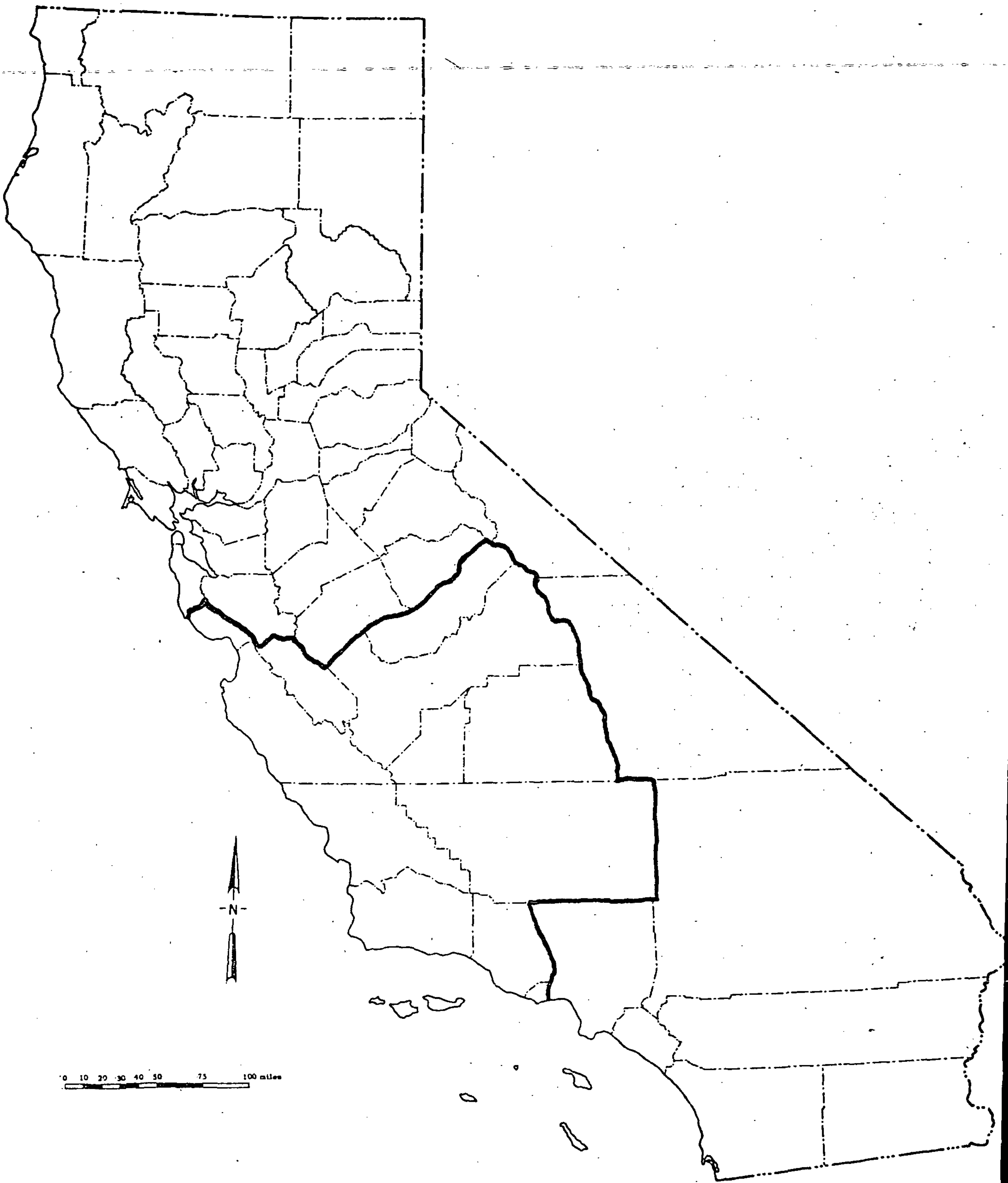


Figure 6.1. Central Regional Test Site, California.

zone to the north and south (Figure 6.1). The study site basically extends from Monterey to Ventura Counties, north and south respectively, and from the coast on the west to the crest of the Sierra Nevada Mountains in the east. Areas of integrated intercampus overlap extend to San Francisco in the northern coastal zone and Santa Monica in the south. It is within this broad regional context that the studies reported on here have been carried out. The following sections of this report are provided to indicate the specific nature of these studies and progress which has been made in conducting them.

6.1 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

6.1.1 Population Estimation

Every ten years, the U.S. Bureau of Census carries out a massive, expensive, and time-consuming analysis of the population of the United States. While the results of the census are statistically accurate and useful in the period immediately following the collection of the data, they can obviously become outdated and inaccurate owing to the lag time before the census data are published, the ten year interval between censuses, and the rapid growth characteristics of many urban areas. Those aware of this tendency towards statistical obsolescence in the real world of dynamic population growth have voiced the need for an interim method of updating census information. Hence, the general purpose of this study is to develop an accurate and inexpensive method to estimate inter-censal population change in urban areas.

Before the present study was initiated, a thorough search of the professional literature on population estimation was undertaken. The

results of this search were disappointing owing to the small quantity of material discovered and the general lack of accuracy exhibited by the existing methods. Nevertheless, several papers provided valuable background for the present study and serve as standards by which a developed methodology can be compared.

The remainder of this section concerns a general description of the present study including discussion of a proposed methodology for population estimation and the results obtained from applying this method to four urban areas. Also included is a preliminary evaluation of this method based on the results obtained thus far from its application.

6.1.1.1 Methodology

It was decided that the primary data source for this study of population estimation would be aerial photographic imagery. This decision was based upon three factors: (1) the relatively low cost of aerial photographic imagery compared to conventional census-taking methods; (2) the ease of obtaining such imagery from governmental or private sources; and (3) the advantages associated with the synoptic view inherent in aerial photographic imagery. It was also decided that a method for population estimation should be equally applicable to urban areas of all sizes and of differing cultural-environmental settings. Therefore, twenty cities in central and southern California were chosen for which NASA high flight imagery was available, and which represented a wide range of sizes and cultural/environmental situations. The twenty cities are listed in Table 6.1 according to six size categories.

TABLE 6.1. POPULATION ESTIMATION STUDY CITIES

City	County	Pop.*
SIZE CATEGORY 1: Over 125,000		
Fresno	Fresno	165,990
Santa Barbara Area:	Santa Barbara	128,215+ (est.)
Santa Barbara (70,215)		
Goleta (50,000 est.)		
Montecito (8,000 est.)		
SIZE CATEGORY 2: 75,000-125,000		
Oxnard Area:	Ventura	85,520+
Oxnard (71,225)		
Port Hueneme (14,295)		
Concord	Contra Costa	85,423
Monterey Area:	Monterey	82,090+
Seaside (35,935)		
Monterey (26,302)		
Pacific Grove (13,505)		
Carmel-by-Sea (4,525)		
Del Rey Oaks (1,823)		
SIZE CATEGORY 3: 30,000-75,000		
Bakersfield	Kern	69,515
Salinas	Monterey	58,896
Ventura	Ventura	57,964
Thousand Oaks	Ventura	35,873
Santa Maria	Santa Barbara	32,749
SIZE CATEGORY 4: 10,000-30,000		
San Luis Obispo	San Luis Obispo	28,036
Visalia	Tulare	27,482
Camarillo	Ventura	19,219
Santa Paula	Ventura	18,000
Tulare	Tulare	16,235
Hanford	Kings	15,179
SIZE CATEGORY 5: Under 10,000		
Paso Robles	San Luis Obispo	7,168
Morro Bay	San Luis Obispo	7,109
Carpinteria	Santa Barbara	6,982
Coalinga	Fresno	6,161

*1970 Census

The preliminary methodology, which was devised for estimating the population size of the twenty cities, consists of a simple function relating the measured area of three dominant residential land use types and the characteristic spatial population densities associated with each. The measured area of residential land use types can be obtained from aerial photography at any time in the inter-censal period. Characteristic population densities for each residential land use type can be extracted from the most recent U.S. Census. The areal data from aerial photography are then combined with the characteristic spatial population densities to yield an estimated population for the area under study.

For the present study, the following aerial photographic imagery was used:

1. NASA high flight 70mm black-and-white panchromatic (red and green bands) photography, flown April 4, 1971.

2. NASA high flight 9 x 9 inches, color Infrared photography, approximate scales 1:120,000 and 1:60,000, flown April 4, 1971.

This imagery was considered optimal because it was flown less than 1 year from the time that census data were collected for each study city.

Each of the twenty cities will be mapped from optically enlarged 70mm black-and-white imagery according to the following land use system:

R_1 - Single family residence,

Rm - Multi-family residence,

Tp - Trailer park residence,

C - All commercial or industrial uses.

The 9 x 9 inch color infrared imagery will be used primarily to supplement basic land use interpretation from the 70mm imagery. Ground truth will be used to check the accuracy of interpretation in twelve selected cities. The area devoted to each mapped land use will be measured for each city with a compensating Polar Planimeter. Thus, each urban unit would be represented according to the area devoted to each of the mapped land uses.

In order to obtain characteristic spatial population densities for the three residential land use types, 1970 U.S. Census Block Data will be used. Random samples of spatial population density will be taken from areas devoted to each land use in the study cities. The spatial population density figures obtained from the random sampling will be averaged to obtain characteristic population densities for each residential land use type.

Once the area of each land use type is measured and the characteristic spatial population density of each land use type calculated, the population of an urban area will be computed according to the following simple function:

$$P = A_{R_1} \cdot D_{R_1} + A_{Rm} \cdot D_{Rm} + A_{R_{TP}} \cdot D_{TP}$$

where P = total estimated population; A_{R_1}, A_{Rm}, $A_{R_{TP}}$ = Areas devoted to each land use type; and D_{R_1}, D_{Rm}, $D_{R_{TP}}$ = characteristic spatial population densities associated with each land use type.

6.1.1.2 Analysis of Four Cities

For this report, four cities have been chosen to illustrate the preceding methodology. The four cities represent a medium range of

population size and are located in relatively diverse cultural/environmental settings. An early decision was made to include the entire contiguous urbanized area, both incorporated and unincorporated, as an urban unit rather than attempting to delimit city boundaries (which often change rapidly in time). Therefore, the population figures listed for the four cities (see Table 6.2) represent the population of the incorporated city plus the population of the suurounding urbanized area.

Figure 6.2 is an example of a city, Salinas, as mapped according to the four land use categories from the 70mm black-and-white imagery. Few problems were encountered in the interpretation/mapping process and supporting ground truth field work indicated that the land use maps were generally quite accurate. An exception was that small, isolated apartment units, and older homes which have been converted to apartments, tended to be underestimated and classified with single family residence (R_1). Table 6.3 shows the measured area in square kilometers of each land use category for each of the four study cities.

In order to calculate the characteristic spatial population densities for each of the residential land use types, random subsamples of spatial population densities were taken from each residential land use category for the four study cities. The results of the random subsampling process were averaged for each residential land use category in each city yielding the characteristic spatial population densities listed in Table 6.3.

The measured area for each residential land use category was then combined with its corresponding characteristic spatial population density

TABLE 6.2. URBAN AREA POPULATION FOR FOUR STUDY CITIES*

Information Category	Incorporated Unit Population	Urban Unit Population
Fresno	165,990	259,028
Bakersfield	69,515	180,263
Santa Barbara	70,215	126,580
Salinas	58,896	58,896

*1970 Census

TABLE 6.3. URBAN LAND USE AND POPULATION DENSITY

Information Category	Urban Land Use Data							
	Fresno		Bakersfield		Santa Barbara		Salinas	
	Measured Area (Km^2)	Spatial Population Density (People/ Km^2)	Measured Area (Km^2)	Spatial Population Density (People/ Km^2)	Measured Area (Km^2)	Spatial Population Density (People/ Km^2)	Measured Area (Km^2)	Spatial Population Density (People/ Km^2)
Single-family Residence (R_1)	74.490	2,550	53.701	2,924	33,561	3,511	12.687	3,502
Multi-family Residence (Rm)	4.777	8,173	1.034	8,535	3.085	7,327	.766	12,344
Trailer Parks (Tp)	.974	6,449	.679	6,449	.365	6,449	.152	6,449
Commercial (C)	9.685	0	19.946	0	15.985	0	5.897	0

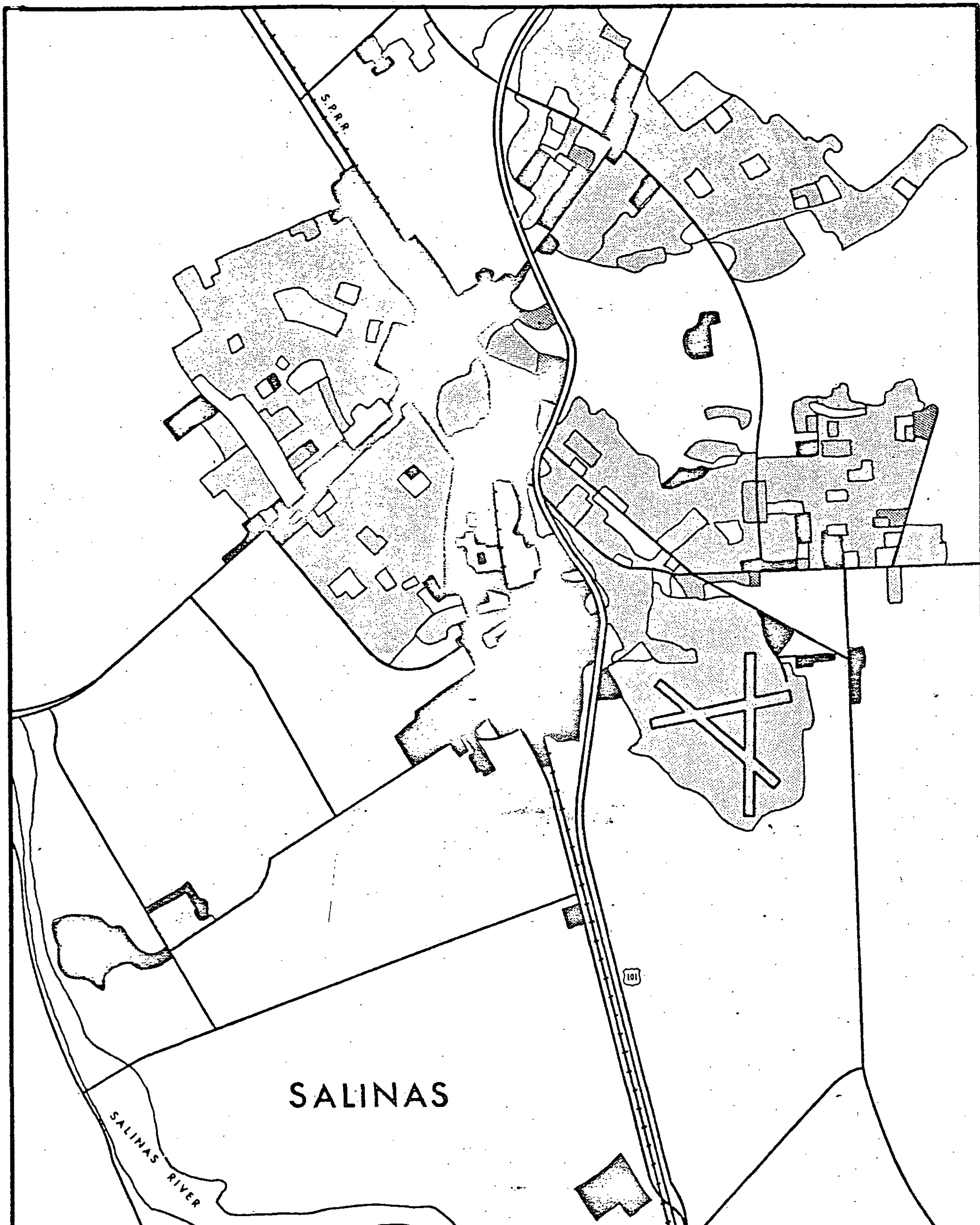


Figure 6.2. Salinas Urban Land Use Map.

URBAN LAND USE LEGEND

OPEN SPACE

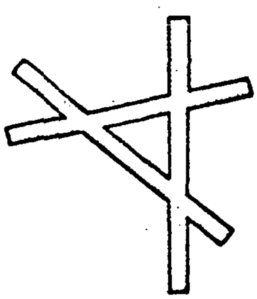
PUBLIC

R_1

Rm

TRAILER PARK

COMMERCIAL/INDUSTRIAL



AIRPORT (PUBLIC)

Figure 6.2. (Continued)

for each of the four cities according to the previously described mathematical function. The resulting estimated population was then compared with the 1970 population of each urban unit and the percent error calculated (see Table 6.4).

6.1.1.3 Evaluation

Based on the experience gained in the preliminary test of the proposed method of population estimation, it appears that a generally applicable method for estimating urban population can be developed. The percent error found in the four initial test cities ranged from 12.8 percent to 5.57 percent, figures much smaller than those obtained by other researchers such as Holz, et al (1969) and Wellar (1969).

The percent error encountered in this initial test of the proposed methodology can probably be reduced through re-examination of the aerial photography in order to re-map the cities at a larger scale. This would allow smaller features such as isolated apartments to be more accurately identified and measured. Also, the four category land use system should be expanded to include the wide range of single family residential lot sizes encountered within any single urban unit. This last modification of the proposed methodology would greatly increase the accuracy of the estimated population in an urban unit such as Santa Barbara which has an especially wide range of residential lot sizes (ranging up to several acres/home) within the urban area.

It is anticipated that, with the completion of the larger study of twenty California cities and possible minor modifications of the proposed methodology, an accurate and inexpensive method of estimating

TABLE 6.4. POPULATION ESTIMATION DATA

	Population Data			
Information Category	Fresno	Bakersfield	Santa Barbara	Salinas
Estimated Population	235,270	170,226	142,789	54,866
Actual Population	259,028	180,263	126,580	58,896
Percent Error	9.17% (-)	5.57% (-)	12.80% (+)	6.84% (-)

inter-censal urban population using conventional aerial photography and U.S. Census data will be developed.

6.1.2 Kern County Cultivated Land Study

6.1.2.1 Objective

The principal objective of this study was to determine the utility of small scale aerial photography for differentiating cultivated cropland and non-cultivated cropland in Kern County. A determination of the amount of cultivated land, in an area where irrigation is important, is needed to ascertain potential for expansion of cultivated acreage, assess requirements for irrigation water, and to assist general planning of the water resources of an area.

6.1.2.2 Procedure and Analysis

The area under investigation was Kern County, California, an area that is heavily dependent on irrigation water for agriculture. With the recent acquisition of water from the California State Water Project, this area will undoubtedly experience expansion of cultivated land. Hence, it is vital that planners have ready access to data relating to the amount of land under irrigation, poorly drained land, etc.

The photography used in this study was NASA color infrared, 70mm high altitude photography (approximate scale, 1:600,000), imaged in 1971.

The first step was to interpret and record, on an acetate overlay, the cultivated and non-cultivated areas in the County. Cultivated land included all land presently under cultivation, cleared pasture land, ploughed land, and land in a bare soil condition. Non-cultivated land included forests and woodland, urban, and extractive activities.

Interpretation was carried out visually with the aid of a 8x magnifier. In many instances, interpretation results were checked with NASA 1:120,000 high flight photography.

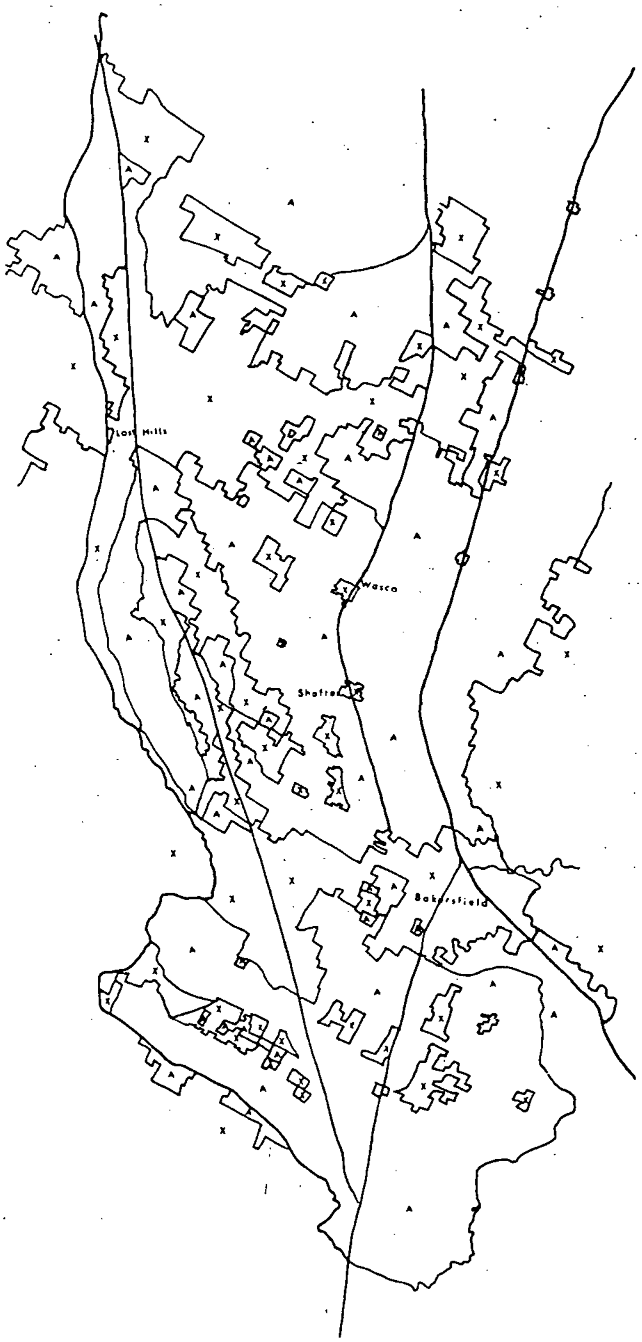
In the course of mapping, variations were noted in some agricultural areas between very poorly drained land and land under irrigation; the former was eventually classified non-agricultural.

The interpretation data were mapped (see Figure 6.3) and cultivated areas measured, using a planimeter. The resultant figure of 753,369 acres was compared with a Kern County 1969 Crop Survey figure of 746,104 acres of irrigated land, a net difference of 7,265 acres. Selected areas (nodal points) were measured and compared by the Kern County Water Agency. The results obtained indicated that there was an overall error of 3.2 percent in the data extracted from the high flight photography.

6.1.2.3 Conclusion

From the results of this study, it can be concluded that high flight aerial photography is a feasible data source for the determination of cultivated and non-cultivated land. It appears, from the Crop Survey figures for certain selected areas, that some poorly drained land had been included under cultivated land. However, if a 1971 Crop Survey of the area was available, it would be possible to determine where and why the photo interpreter and the Crop Survey figures differ. The capability to accurately perform this type of inventory on a yearly basis would be of great importance to planning and management decisions regarding the use of an area's water resources.

KERN COUNTY



KEY:

A - Agricultural Land

X - Non-Agricultural Land

Source - 70mm NASA High Flight Photography

Figure 6.3. Kern County Agricultural (Cultivated Land) Land Use Map.

6.1.3 West Side Vegetation

6.1.3.1 Introduction

A vegetation map of the West Side has been completed using 1:120,000 scale color infrared photography in conjunction with intensive ground reconnaissance and sampling surveys. In addition to the map, descriptions of each vegetation type have been prepared and an effort was made to determine the European land use history with an eye to explaining some of the present day patterns.

6.1.3.2 Methods

The color infrared imagery used for mapping purposes indicated very complicated vegetation patterns. The cultivated areas were easily distinguished owing to their distinctive color and geometry. Riparian and flood plain vegetation were similarly conspicuous. However, spectral responses from the alluvial plains and the lowlands showed considerable internal variation, and, consequently, it was not possible to differentiate them without reference to ground truth. Using ground truth data, the vegetation from these zones could then be separated with relative ease. Moreover, many patterns on the photographs did not indicate significant differences in the plant cover, whereas ground reconnaissance revealed communities on both the alluvial fans and within the bottom lands which could not be distinguished on the photographs were probably due to the close physiognomic and taxonomic relationship of the dominant shrub species in the different communities, and their relatively sparse cover.

The annual community, which covers a much greater proportion of the ground, and is dominated by the same species through large areas, can

often be identified on the photography. Where this cover is significantly less, in the lowland areas, it is closely correlated with saline and alkaline soils and a distinct perennial flora. The characteristic spectral response of these areas is probably attributable to the greater exposure of bare soil and its distinctive visual characteristics. On alluvial fans, where annual cover approaches 100 percent, it is not possible to predict with much accuracy areas where the shrub canopy is present or absent. The floodplain vegetation, dominated by mesquite (but also with cottonwood, willow and occasionally sycamore) is readily differentiated and may be mapped quite accurately.

Color infrared photography at the scale of 1:120,000 was found to be the most satisfactory imagery available. No finer distinctions could be made using larger scales (e.g., 1:60,000), while true color imagery, on the whole, displayed a lesser degree of distinction between the vegetation communities. It is believed that the same degree of accuracy, as achieved using 1:120,000 scale, might be as easily attained with still smaller scales.

Once the major vegetation boundaries had been mapped from photography and ground reconnaissance, data were collected to describe the nature of the communities in more detail than presently available. As a large area had to be covered, a rapid sampling method was essential. Reconnaissance indicated that there was very little variation in the vegetation type as distance from the road network increased. Accordingly, it was decided that the road network, which is laid out according to section boundaries or other survey lines, rather than topography, would

make satisfactory transect lines. Location of samples was determined by constructing random lines over the road network and fixing all points where intersections occurred between roads and constructed lines. At these points samples were taken consistently at a distance of 100 meters from the road sides. The sample transect consisted of a line of 40 meters in which species occurrence was noted in each square meter. General descriptions were also gathered for each site, and estimates of percent cover were made. However, as field work was done during the summer months after an exceptionally dry season, the degree of deterioration of the annual ground cover was such that a reliable indication of the extent of the cover for the previous winter could not be made. Consequently, the "Winter Annuals" community is not included on the resultant map (see Figure 6.4).

6.1.3.3 Vegetation Types

Desert Saltbush

The desert saltbush (*Atriplex polycarpa*) is the most widespread shrub species on the grazing land of the West Side. It occurs on the alluvial fans, dissected uplands, and the raised sections of the bottomlands along the axis of the valley. Its ability to tolerate saline and alkaline conditions is indicated by its occasional presence on the lowland soils. Only on the better-drained locations does it become the dominant shrub, covering extensive tracts with very few associated shrub species. Typically the community has an almost complete ground cover of annuals, of which filaree (*Erodium sp.*) and brome grass (*Bromus sp.*) are the dominant species (as indicated in Table 6.6).

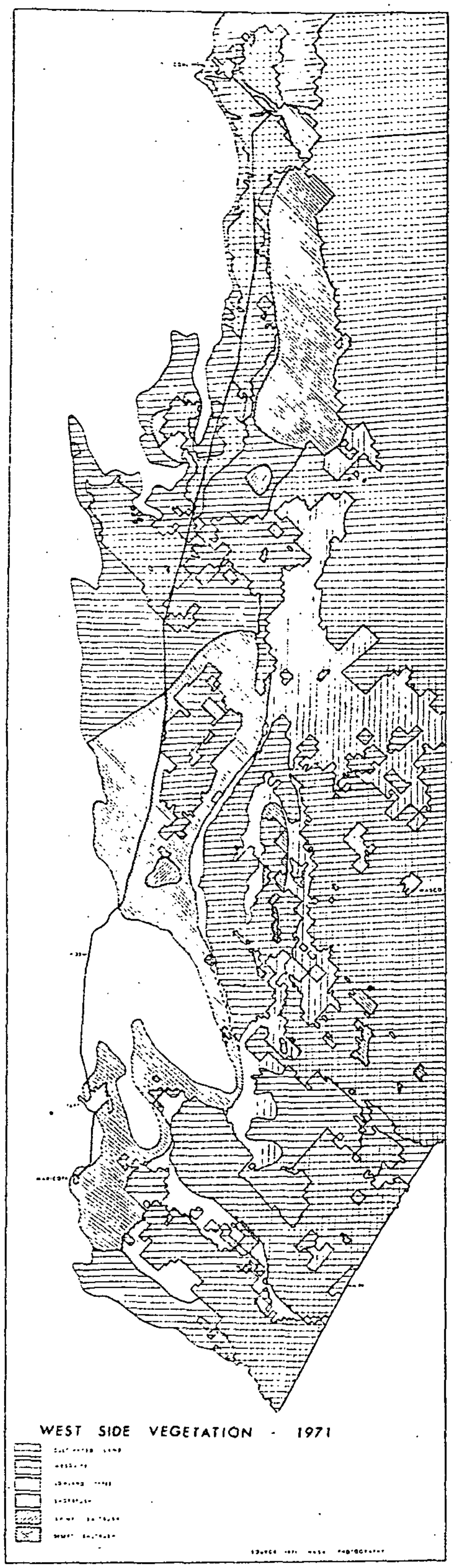


Figure 6.4. West Side San Joaquin Valley Vegetation Communities Map.

Key to Tables 6.5 and 6:7 Through 6.11

Tables 6.5 and 6.7 through 6.11 show the frequency distribution of dominant flora within the particular vegetation community for forty meter sample transects. The numbers along the left margin of the tables indicate the sample transect. The numbers (1-40) along the top of the tables indicate the specific one square meter blocks which were sampled along the entire length of the transect. For example, Table 6.5 shows the frequency distribution of dominants (perennials) in the Desert Saltbush Community. The degree of dominance of *Atriplex polycarpa* is evidenced by the high frequency of occurrence of the letter b in the table. The absence of letters in some squares indicates the absence of shrubby vegetation within that sample unit, and tends to emphasize the open nature of the community.

Key to Letter Symbols in Tables 6.5 and 6.7 Through 6.11

a *Suaeda fruiticosa*

b *Atriplex polycarpa*

c *Atriplex spinifera*

d *Frankenia grandifolia*

e *Allenrolfea occidentalis*

f *Distichlis spicata*

g *Sporobulus airoides*

h *Haplopappus sp.*

i *Salsola kali*

k *Atriplex sp.*

l *Gutierrezia bracteata*

m *Artemisia californica*

TABLE 6.5. DESERT SALTBUSH COMMUNITY

Sample No.	Meters 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	b	b	b	b			b		b	b	b				b	b				b										b	b	b	b	b	b	b	b	b	b	b
2							b	b									b	b																						
3			b	b	b	b	b	b	b	b	b	b	b	b	b		b	b			b	b	l	l		b	b	b	b	b		b								
4	c															c									c	c		b	b	b		b		b	b					
5				b												b	b	b		b					b	b										b	b			
6	m						b	b																				b	b											
7								b																			b								b	b				b
8																																								
9																			b	b												b	b	b						
10	b	b	b	b	b	b	b	b	b	b	b			b	b			b	b	b	b				b	b	b	b	b	b	b	b	b	b	b	b	b		b	b
11	b	b	b	b	b																					b														
12																	b	b																				b		b
13											b	b	i																						b	b				
14																																								
15								b	b	b										b	b	b																		

TABLE 6.6. GROUND COVER PLANTS IN TWO VEGETATION TYPES

	Desert Saltbush							Winter Annuals												
Sample No.	1	2	13	15	17	26	30	3	4	5	6	7	8	11	14	18	25	27	28	29
Bromus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Erodium	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cryptantha	x	x						x	x	x	x		x		x					
Lepidium	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Amsinkia		x	x			x						x		x	x					
Haplopappus		x																		
Setaria								x			x						x			
Compositae 1									x	x										
Compositae 2				x	x				x	x				x	x					
Plantago 1									x											
Gramineae 1					x	x			x	x		x			x			x		
Gilia									x		x									
Leguminosae					x	x			x						x		x			
Gramineae 2										x									x	
Plantago 2						x	x			x	x				x					
Hordeum					x								x					x		
Orthocarpus						x							x							
Gramineae 3														x		x				
Gramineae 4			x												x					
Phacelia			x	x											x					
Brassica			x																	
Gramineae 5			x	x											x					
Euphorbia																x				
Gramineae 6																	x			
Barassica																	x			
Taraxacum						x	x										x			
Compositae 3																	x			
Compositae 4						x											x			
Eschscholzia																		x		
Lupinus																		x		
Trifolium																				

TABLE 6.7. WINTER ANNUALS COMMUNITY

Meters

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1		i																				i																		
2		i								i	i			i	i													i												
3		i	i									i				i			i	i												i			i	i	i			i
4		i							i	i			i									i	i	i	i			i	i	i	i									
5																																								
6			i	i																							i						i		i	i				
7	i	i	i	i	i	i		i			i	i	i					i			i			i			i	i	i	i	i			i						i
8																																		i	i					
9																																								

TABLE 6.8. SAGEBRUSH COMMUNITY

Meters

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1											i																													
2																								m																
3																																								
4																																								
5		m	m		m	m																				m	m													m
6				m																m						m														

TABLE 6.9. SPINY SALTBUSH

Meters

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1																											c	c	c						c		c	c		
2																								c	c	c														
3													c											c	c															
4						c																						i	i		i									
5	c		c	c		c	c	c	c	c	c				c	c	c	c	c				c				c	c	c d	c d	d									

TABLE 6.10. LOWLAND TYPES COMMUNITY

Meters

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1				a	a	a	a	a			a	a									a					a	a			a	a									
2						b	b										a	a	a c	c	c				a				a	a		a	a		a	a		a		a
3																																								
3	a	a	a	a		a	a	a	a		f			a g	a g	g	a d g	a g	g	g				d		e			a d	a d	d g				h	b h	b	d		d
4			a	a	f	f	f	f	f	f																														
5					e	e	a e	a																																
6									h	d h	d									d	a	a d	a d	a	a	a	a	a	a d											
7	f	f	c	c b	f b	f b	f	f			f						b	b				a	a	a			a	a			f	f	a f	a f	a f	b f	b f	b f	b f	b f
8															e	e	e	e	e												e	e	e	e			e	e	e	e
9						a		a	a						a	a												a	a			a	a			c			c	
10	a	a	a	a	a		a	i				a								a																				
11	i	k	d k	a i k	a i k	a i	i	a	i k	i k	a	i	i	i		a		i			a			i	i				i	i		i	i	i	i	i		i		
12	i	i	i	i	i k	k	i k	k	i	i	i	i k	i	i	i	i	i	i	i	i	i	i	i	i	i	i		i	i	i	i	i			i	i		i	i	i

TABLE 6.11. MESQUITE COMMUNITY

Meters

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f			f	f	f	f	f					f	f		f		f	f	f	f
2																																								
3																																				h	h	h	h	
4								h	h	h	h																h													
5																	f		f																					
6					a			a	a	a			a	a																										
																			c	c	c																			
7																														g										
7		f	f	f						f		f	f			f														f	f	f								
		a		a	a							a	a		a		a	a	a				a	a		a	a					a	a		a	a	a		a	
			h	h											h																									
								g							g																									

The degree of dominance of desert saltbush is indicated in Table 6.4, which also reveals that there is a great variety in density. Values of presence in each square meter of the 40 meter transect vary from 0 to 32, though in most transects less than 25 percent of the sub-units contained a shrub (indicating the open nature of the community).

Piemeisel and Lawson (1937) mapped this community, and concluded it was more extensive in pre-european times, having been reduced in areal extent by cultivation, clearing in the oil fields, and grazing activities. The aridity of the West Side south of Coalinga has prevented dry farming, although irrigated cropland which is of recent origin, is presently at its greatest areal extent. Destruction of this shrub community, by crop cultivation followed by abandonment, does not apply to the area under consideration. However, the clearing of shrubs in oil fields to reduce fire risk has undoubtedly occurred. Early photographs of oil fields show bare soil. Where sites could be identified and revisited today, desert saltbush has been able to satisfactorily reestablish, forming communities which are indistinguishable from those not subjected to clearing. This species shows a degree of weediness, as it seems to invade disturbed areas such as construction sites and roadsides where competition is reduced and runoff might be increased. Ranchers are well aware of the regenerative powers of desert saltbush in wet years on land that has been burned or overgrazed.

Field experiments concerned with saltbush regeneration have been conducted on the Temblor Range Experiment Station over a period of years. From these experiments, some important ecological relationships were

demonstrated. Strips of range were disced to reproduce conditions of cultivation, and pruned with a cotton harvester, to approximate grazing. The frequency and vigor of plants before and after treatment were compared. Results suggested that cultivation may actually lead to an increase in the shrubs, presumably by removing competition. Pruning on the other hand led to a deterioration in the perennial shrubs, suggesting that grazing might in this case lead to the reduction of the shrub community to the advantage of the understory of the annual grasses and herbs.

Since the last recorded mapping of this community, in 1935, further contractions in its extent have occurred. The present boundary between this vegetation type and that of Winter Annuals, south of Kettleman City, is marked by areas where 60 percent of the shrubs appear to be dead or dying. This suggests that still further retreat may be occurring, stimulated perhaps by two consecutive dry years. The present distribution of desert saltbush is confined to the alluvial fans, which are most affected by the rain shadow of the Temblor Ranges, or on dissected anticlinal ridges, where shallow soils and rapid run off serve to reduce rainfall effectiveness. Only here does this deep rooted perennial seem to have competitive advantage over the aggressive, but shallow-rooted annual grasses and herbs.

Winter Annuals

The community composed of only annual plants shows little structural or floristic difference from that of the understory of the Desert Saltbush vegetation type (see Table 6.7). Although consideration of the annual flora is not within the scope of this study, a brief survey

indicates little floristic difference between the two communities. Table 6.7 shows that the most ubiquitous annuals, filaree and brome, were recorded in every sample (in both communities) and in fact probably make up 90 percent of the biomass of the plant community. No commonly occurring plants are restricted to one or the other of the types.

Both filaree and brome are introduced species (Munz, 1968) which appeared very early in the period of European occupation. Fremont, for example, noted the presence of filaree (<u>Erodium cicutarium</u>) in the Central Valley in 1844 (Fremont, 1945). In more moist regions it is believed that annuals such as these replaced native perennials. It is unlikely that perennial grasses were an important component of the flora of the southern West Side, as they would not be able to withstand the arid conditions. The pre-European flora, then, was presumably composed of the native grasses which are now of only minor importance among the understory plants.

Russian Thistle (<u>Salsola kali</u>) is worthy of special mention because it can become a serious weed, and can also adopt a perennial habit. Its frequent occurence in the Winter Annual areas, and its rarity in regions where other shrubs are present, may be a significant relationship, reflecting the pioneer nature of the species and its inability to compete with other perennial plants.

Annual grasslands, as presently constituted, are a post-European phenomenon. However, since 1935, their extent has increased at the expense of the saltbush communities. This is thought to be a result of grazing

pressure leading to the destruction of the perennial shrubs in the moister regions where grazing pressure is strongest and where the xerophytic characteristics of the saltbush species have least competitive value.

Sagebrush

This shrub community is similar in structure to others within the study area in that: (1) it is dominated by a single perennial plant, the California sagebrush (Artemisia californica); and, (2) it has an understory of annual plants composed of the same species with similar relative abundances as do other alluvial fan communities. For this reason, the sagebrush type can not be differentiated at all on the available photography.

Many historical accounts of the Central Valley mention the 'Sagebrush.' However, this probably reflects the practice of applying this common name to any grey-green, low shrub, rather than indicating a widespread replacement of Artemisia by other shrubby species over the western rangelands. Earlier surveys noted the occasional presence of sagebrush on the West Side, but nowhere was it noted as a dominant shrub. Hence the present extent of this vegetation type on the alluvial fans of the Tehachapi Mountains may represent a recent spread of the species. On the other hand, it may represent an oversight or have been considered to have occupied an area too small to be mapped.

If the Sagebrush community is a recent invasion, experience elsewhere suggests it may be a result of management practices (Robertson and Kennedy, 1954). Because sagebrush is a poor browse, preferential

grazing by cattle tends to increase the abundance of *Artemisia*. The present boundary between Sagebrush and Desert Saltbush types (as discernible on the ground) is a remarkably abrupt one, though it does not correspond to a fence line or any other obvious cultural division.

Spiney Saltbush

This community is one of the most restricted on the West Side. It is dominated by *Atriplex spinifera* forming a very low and incomplete shrub canopy. Much of the land once occupied by this species is now under cultivation; hence, it is difficult to determine the original areal extent from the fragments of the distribution which remain. It is probable that the community occupied a zone at the base of the alluvial fans between the Desert Saltbush of the higher slopes and the Lowland Types of the flat bottomland. Soils in this area have some problems associated with poor drainage and high salinity. Other perennial plants occasionally found in this community are those with salt tolerance. The understory of annual plants appears to be adversely affected by the properties of the soil; hence, much land is bare, with some evidence of salt scalds.

The 1935 vegetation map indicates that the community was previously more extensive than today, even on land which is still uncultivated. This explanation may lie partly in the difficulty of defining the community in precisely the same way as Piemeisel and Lawson, since they offered only a descriptive account of the type. However, in 1935 a large section of the southern Kettleman Hills was recorded as dominated by this vegetation type. Today, only a tiny pocket of shrub vegetation exists, which is in poor condition and apparently disappearing. The majority of the

area is presently covered by only winter annuals. Grazing pressure is a possible explanation of the retreat of this species. However, the species is considered a poor browse as it is spiney and, unlike desert saltbush, does not produce new growth during summer when range plants are in poor condition.

Lowland Types

This community is by far the most diverse in species content of perennials and annual ground cover. The considerable exposure of the soil and its strongly saline character are thought to be largely responsible for our being able to recognize this community on the photography.

Seep-weed (Suaeda) is the most common shrub, and is only absent in low lying sections, which have conspicuous soil salinity problems, or in the lake beds, where occasional high water levels inhibit the growth of perennial plants. Allenrolfea forms dense stands with no ground cover at all in some poorly drained locations. In Tulare Lake bed, which is now largely under intensive cotton cultivation or casual barley cropping for hay, saltgrass (Distichlis) and Frankenia appear as weeds in the barley fields, and will predominate when water is not available to flood irrigate the hay crop.

The Lowland Types are little grazed, since the shrubs are unpalatable and the annual ground cover is relatively sparse. In the past, the overflow lands such as these were among the most valuable pastures in the lower San Joaquin Valley. But, with the controlling of the waters of the Kern and Kings Rivers and the diversion of water for irrigation on the eastern side of the valley, the bottomlands which

are not cultivated are the least productive in the area.

Mesquite

This community covers the alluvial fan of the Kern River. Near the stream channels, willow, cottonwood, and occasionally sycamore are present, but only mesquite covers extensive areas of the delta. The mesquite develops a so-called running form, where the branches spread laterally, producing a roughly circular thicket perhaps 15 meters in diameter and 5 meters high. Individual trees rarely touch, and owing to their greater vertical height than the sparse, low surrounding shrub vegetation, they are most conspicuous on the photography. The understory is essentially the same as the Lowland Type, where seep-weed is the dominant. In the immediate vicinity of the drainage channels, weedy species are common in the sandy alluvium of the braided stream course.

The extent of the community has not previously been delineated, though it is the most easily distinguished from either ground or air. This may be a result of the increase in area under mesquite over the last 30 years. The species is not widely recognized as an introduced plant (Munz, 1968; Jepson, 1936; Twissleman, 1967). Spanish missionaries commonly made mention of the cottonwood and willow in the Kern River area (Cook, 1958), but made no mention of mesquite, today the most common tree. The early American explorers record the same picture. The earliest mention of mesquite in the San Joaquin Valley is a reference in a newspaper article written in 1877 and quoted in Tracy (1962). The earliest botanical collection appears to be one made by Burtt Davey in 1896 (no. 1756), suggesting the species had invaded the valley at least

by the late nineteenth century. The dispersal of mesquite over extensive areas of the Southwest is considered to be at least in part the result of grazing practices. It is hard to imagine that mesquite could not disperse naturally from the Mojave in pre-European times. Presumably grazing practices rendered the area suitable for establishment of seedlings.

In recent years the declining water table, resulting from increased pumping for irrigation, has caused deterioration of the floodplain vegetation. As early as the 1850's, early American explorers noted extensive areas of dying cottonwoods, probably owing to some natural readjustment of drainage and underground water supplies. With additional water from the California Aqueduct, it is expected that the water table will be stabilized at a level higher than present. The effect of this may lead to further spread of mesquite, at present controlled by the dry conditions.

6.1.3.4 References to West Side Vegetation

Cook, S.F. (1958), "Colonial Expeditions to the Interior of California," Anthropological Records 16:239-292.

Fremont, J.C. (1845), "Report of the Exploring Expedition to the Rocky Mountains in the Year 1942 and to Oregon and California in the Year 1843-44," 28th Congress, 2nd Session, Senate Documents 11:174.

Jepson, W.L. (1936), A Flora of California, Vol. 2, Part 3, Assoc. Student Store Univ. of California, Berkeley.

Munz, P.A. and D.D. Keck (1968), A California Flora, University of California Press, Berkeley and Los Angeles.

Piemeisel, R.L. and F.R. Lawson (1937), "Types of Vegetation in the San Joaquin Valley of California and their Relation to the Beet Leafhopper," U.S. Department Agric. Tech. Bull. 557.

Robertson, J.H. and P.B. Kennedy (1954), "Half Century Changes on Northern Nevada Ranges," Journal of Range Management, 7:117-121.

Tracy, F.C. and G.L. Rodgers (1962), The Tracy Saga, Cardon House, Kern Co., California.

Twisslemann, E.C. (1967), "A Flora of Kern County, California," Wasmann Journal of Biology, 25:1-295.

6.1.4 Coastal Zone Investigation

As part of the three campus (Berkeley, Riverside, Santa Barbara) integrated study of the California Coastal Zone, the Geography Remote Sensing Unit is responsible for the portion of this area extending from Santa Monica in the south to Monterey in the north (see Figure 6.5). The objective of the overall study is the development of a standardized, multi-functional data base for the entire coastal zone. Elements of the data base will include parameters such as land use, landforms, natural vegetation, hydrologic features, etc. A data base of this nature will prove invaluable for resource inventories, anticipation of future urban pressure and movement, service needs, optimum open space elements, planning hazards (i.e., areas of possible flooding and fire), and general planning and management requirements.

The investigation is being conducted in two phases. The first phase involves the development of classification systems for categorizing characteristic parameters in the Coastal Zone. The second phase concerns mapping and testing the classification systems for intensive areas within the Coastal Zone. As a result of Phase II, a series of maps will be produced for the enitre Coastal Zone that will include those parameters needed for a suitable data base.

The first phase has been completed through the coordinated efforts of the three campuses. Significant parameters have been identified for

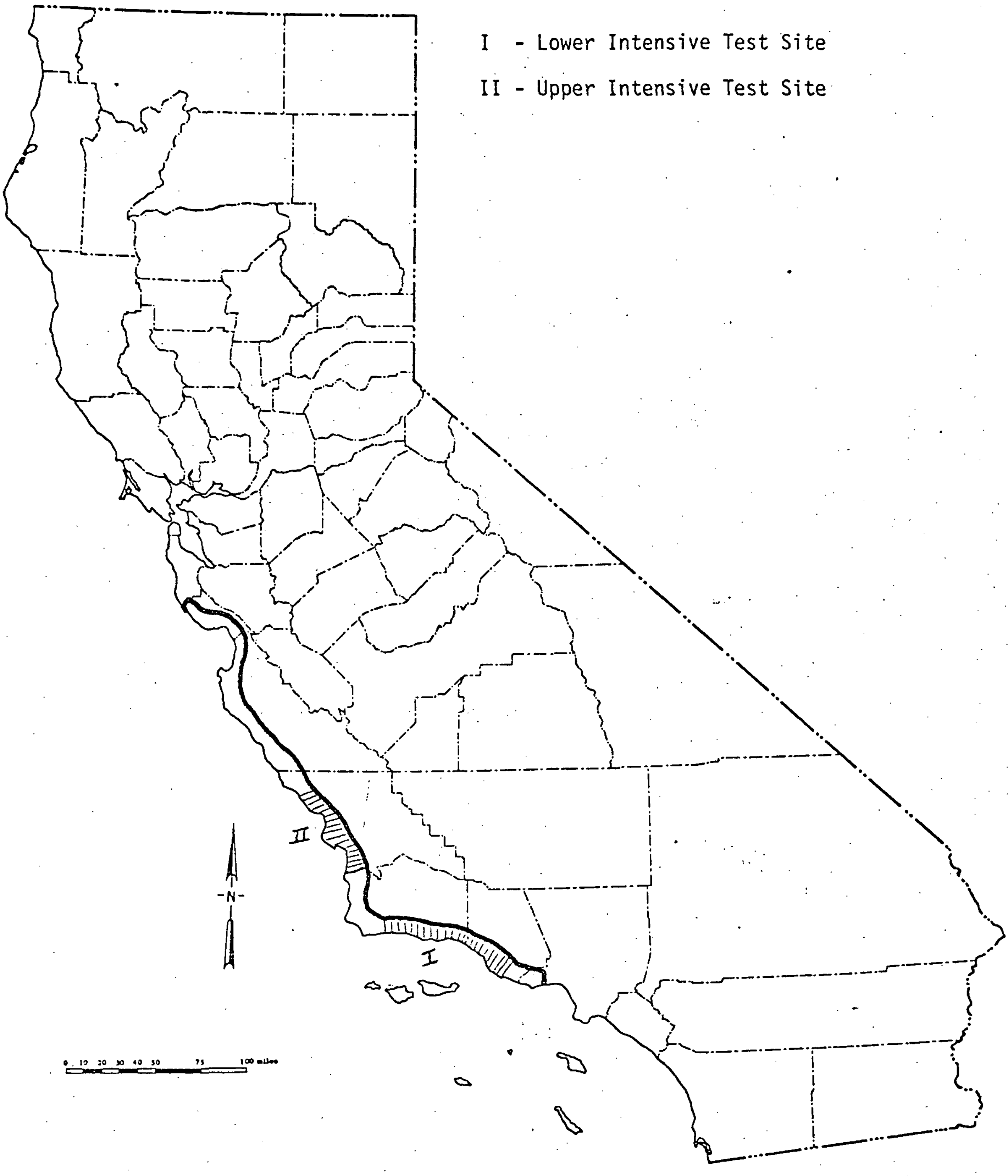


Figure 6.5. Central Coastal Zone.

which data need to be collected. These include: land use, landforms, natural vegetation, and hydrology. Working classification schemes for mapping these paramters have been developed and form the basis for Phase II testing. These systems have been designed to meet three criteria: (1) the categories should be appropriate for collecting data within the Coastal Zone; (2) categories should be compatible with the capabilities of remote sensors to provide data and require minimal use of supplemental information sources; and (3) classification structures should be hierarchal (proceeding from very general to very specific information categories) to reflect and accomodate changes in data provision capabilities owing to the use of varying sensor platforms.

Two intensive areas are being investigated by GRSU to test the various proposed classification systems (see Figure 6.5). The first area (lower test site) extends from the Oxnard Plain in the south to Gaviota in the north. The second area (upper test site) extends from the Santa Maria River in the south to San Simeon in the north. The inland width of both areas is approximately 24 to 32 kilometers. Mapping is being accomplished from 1:120,000 scale color infrared high flight imagery. Direct overlays are being used to extract data. Figure 6.6 is an example of a detailed urban land use map for the city of San Luis Obispo. Figures 6.6 through 6.10 are land use, vegetation, landform, and drainage data base maps which have already been completed for the upper test site in the Coastal Zone (see Tables 6.12 through 6.14 for explanation of symbols). These pilot maps have been shown to planners in Santa Barbara, San Luis Obispo, and Ventura counties. The reaction of the planners to these maps

TABLE 6.12 LAND USE CLASSIFICATION

KEY:

General Category ex. A (Agriculture)
Type within Category ex. t (tree crops)
Specific Type ex. c (citrus)
Total Code: Atc

Note that the more specific notation depends upon ability to identify and additional types and specific types can be added to the system as they are encountered.

	CODE
Agriculture	A
Crops	Ac
Grain Crops	Acg (type)
Horticulture	Ach (type)
Row Crops	Acr (type)
Tree Crops	Act (type)
Livestock	Al
Stock farming (beef)	Alsb
Stock farming (sheep)	Alss
Stock farming (dairy)	Alsd
Rangeland	Ar
Pasture (improved)	Arpi
Pasture (unimproved)	Arpu
Extractive	E
Seawater mineral recovery	Es (type)
Petroleum production fields	Ep (type)
Mining Operations	Em (type)
Public Facilities	G
Governmental-administrative	Ga (type)
Governmental-military	Gm (type)
Cemeteries	Gc

TABLE 6.12 (Continued)

	CODE
Protection- Police & Fire	Gf (type
Hospitals	Gh
Prisons	Gp
Waste disposal (solid & liquid)	Gd (type)
Education	Ge (type)
Parks & Recreation	P
Campground	Pc
Golf Course	Pg
Park	Pp
Stadium	Ps
Marinas	Pm
Resort	Pr
Industrial	I
Primary Conversion	Ip
Steel mill	Ips
Ship building	Ipb
Saw mills (or pulp)	Ipw
Assembly	Ia
Auto	Iaa
Electronic	Iae
Food Processing	If
Canneries-fish	Ifc
Canneries-fruit	Iff

TABLE 6.12 (Continued)

	CODE
Storage	Is
Port warehousing	Isp
Rail warehousing	Isr
Transportation	T
Airports	Ta (type)
Highways	Th (type)
Railroads & Yards	Tr (type)
Canals	Tc (type)
Docks	Td
Commercial	C
Clustered	Cc (type)
Strip	Cs (type)
Residential	R
Single family	Rs
Multi-family	Rm (type)
Non Developed	N
Natural Vegetation	Nv (type)
Idle Land	Ni (type)
Barren Land	Nb (type)
Water Bodies	Nw (type)

TABLE 6.13 NATURAL VEGETATION CLASSIFICATION

Plant Community	Code
I. Aquatic	
A. Marine (Aquatic)	M
1. Nearshore (Kelp and seaweed)	Mn
2. Intertidal	Mi
B. Freshwater (Aquatic)	Fw
C. Marsh	Ma
1. Salt Marsh	Ma_{sm}
2. Freshwater Marsh	Ma_{fm}
II. Terrrestrial	
A. Barren	Ba
B. Strand	Sr
C. Grassland	G
1. Coastal Prairie	Gcp
2. Valley Grassland	Gvg
3. Meadows	Gme
D. Woodland-Savanna	Ws
E. Scrub	S
1. North Coast Shrub	Snc
2. Coastal Sagebrush (soft chaparral)	Scs
3. Cut-over Forest	Scf
4. Chaparral (hard chaparral)	Sc
5. Scrub-Hardwood	Shw
F. Forest	F
1. Hardwood	Fhw
2. Mixed Evergreen	Fme
3. Coniferous	Co
a. Redwood	Co_{rw}
b. North Coast	Co_{nc}
c. Douglas Fir	Co_{df}
d. Pine Cypress	Co_{pc}
G. Riparian	R

TABLE 6.14. LANDFORM CLASSIFICATION

I. Fluvial
   A. River and stream valley
      1. meander
      2. oxbow lake
      3. meander scar
      4. terrace
      5. channel bar
      6. point bar
      7. delta bar
      8. channel filling
      9. natural levee
      10. crevasses
      11. distributaries, passes, or mouths
   B. Deltas
      1. esturine
      2. arcurate
      3. digitate (birdsfoot)
   C. Other
      1. alluvial fan
      2. alluvial cone
      3. bajada
      4. playa
      5. alkali flat
      6. salinas
      7. washes (wadis)
II. Eolian
   A. Dunes
      1. sand shadows
      2. barchan or crescent
      3. longitudinal or seif
   B. Sand sheets

TABLE 6.14. (Continued)

C. Whole backs

D. Deflation basins

E. Caves or arches

III. Waves and Currents

A. Terraces

B. Tidal zone

1. Beach
2. bays
3. inlet
4. sea arch
5. stack
6. bar
7. spit
8. foreland

C. Offshore zone

1. tombolo
2. stack
3. bar
4. spit
5. foreland
6. island

IV. Complex and Compound

A. Mountain

B. Hill

1. monadnock
2. inselberg
3. other

C. Ridge

1. cuesta
2. hogback
3. homoclinal
4. other

TABLE 6.14. (Continued)

D. Plain
   1. lacustrine
   2. outwash
   3. other
E. Water body
   1. lake
   2. lagoon
   3. estuary
   4. tidal marsh
   5. tidal flat
   6. other

V. Other
   A. Karst
      1. sinkhole
      2. uvala
      3. karst plain
      4. bland valley
      5. karst vallet
      6. rise pits
      7. hums
   B. Atolls and reefs
   C. Meteorite craters
   D. Carolina bays
   E. Man made forms
   F. Other

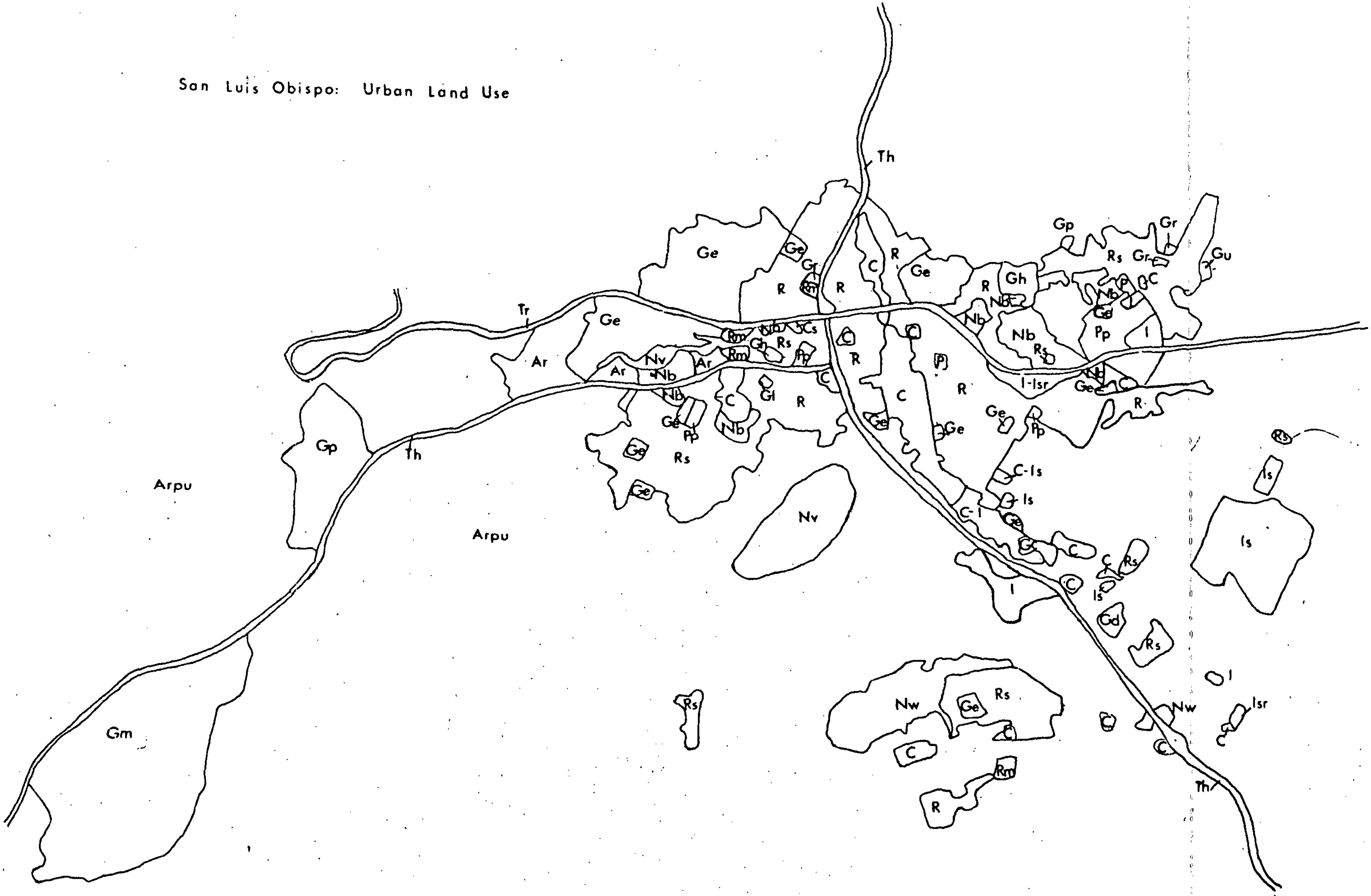


Figure 6.6. Urban Land Use Map of San Luis Obispo County based on NASA color infrared photography, scale 1:120,000.

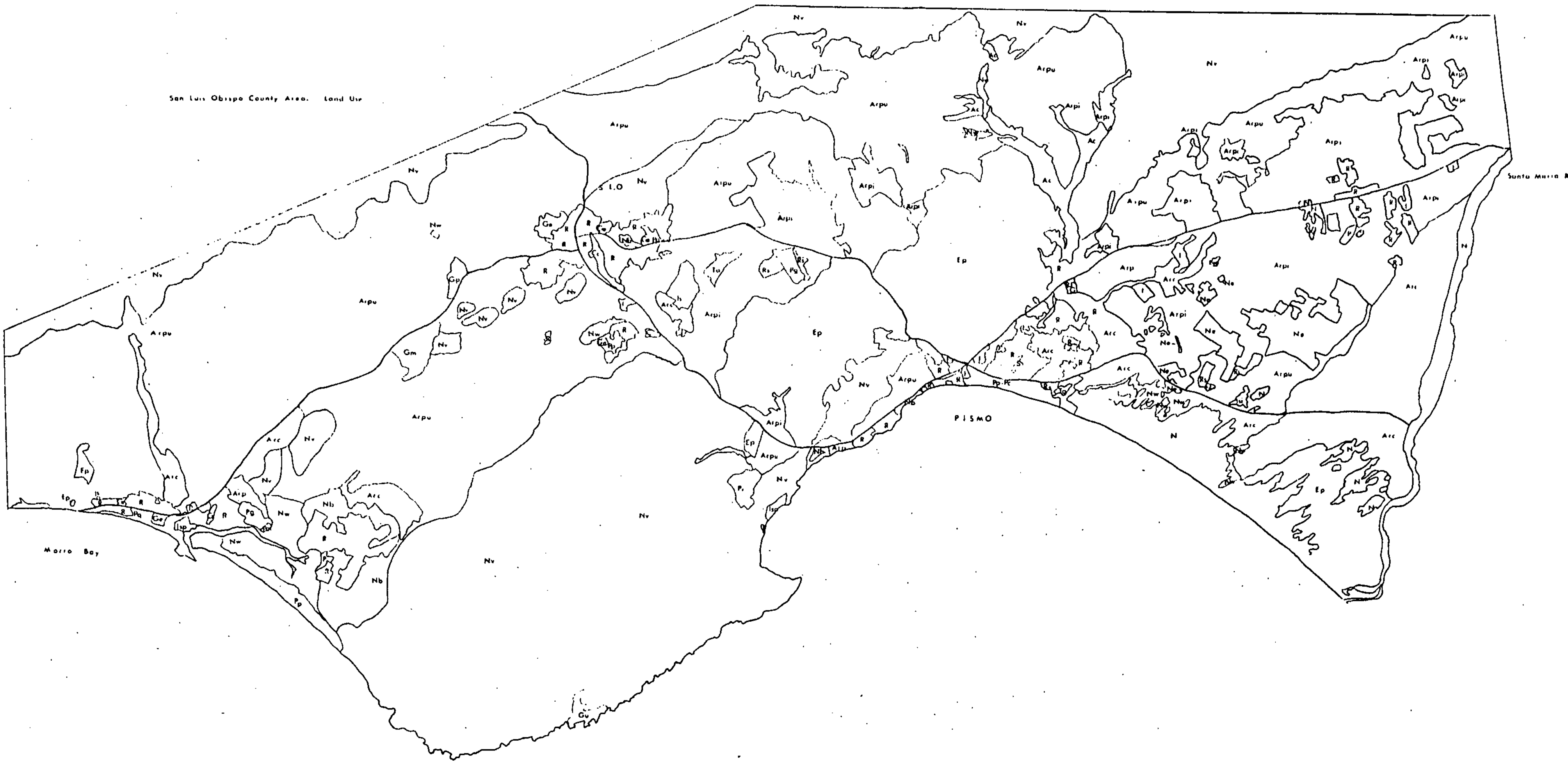


Figure 6.7. General Land Use Map of San Luis Obispo County based on NASA color infrared photography, scale 1:120,000.

Figure 6.8. Vegetation Map of San Luis Obispo County based on NASA color infrared photography, scale 1:120,000.

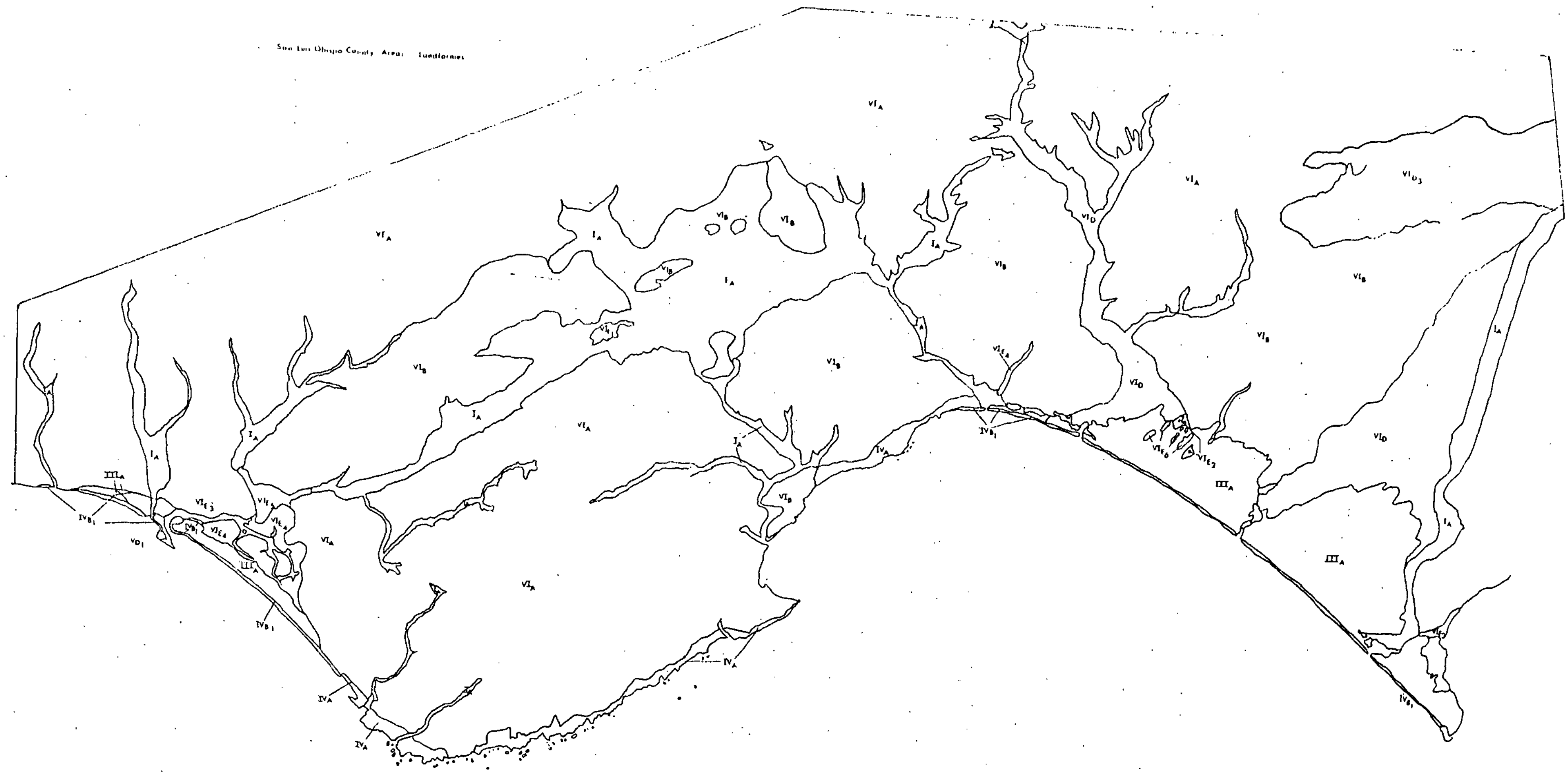


Figure 6.9. Landform Map of San Luis Obispo County based on NASA color infrared photography, scale 1:120,000.

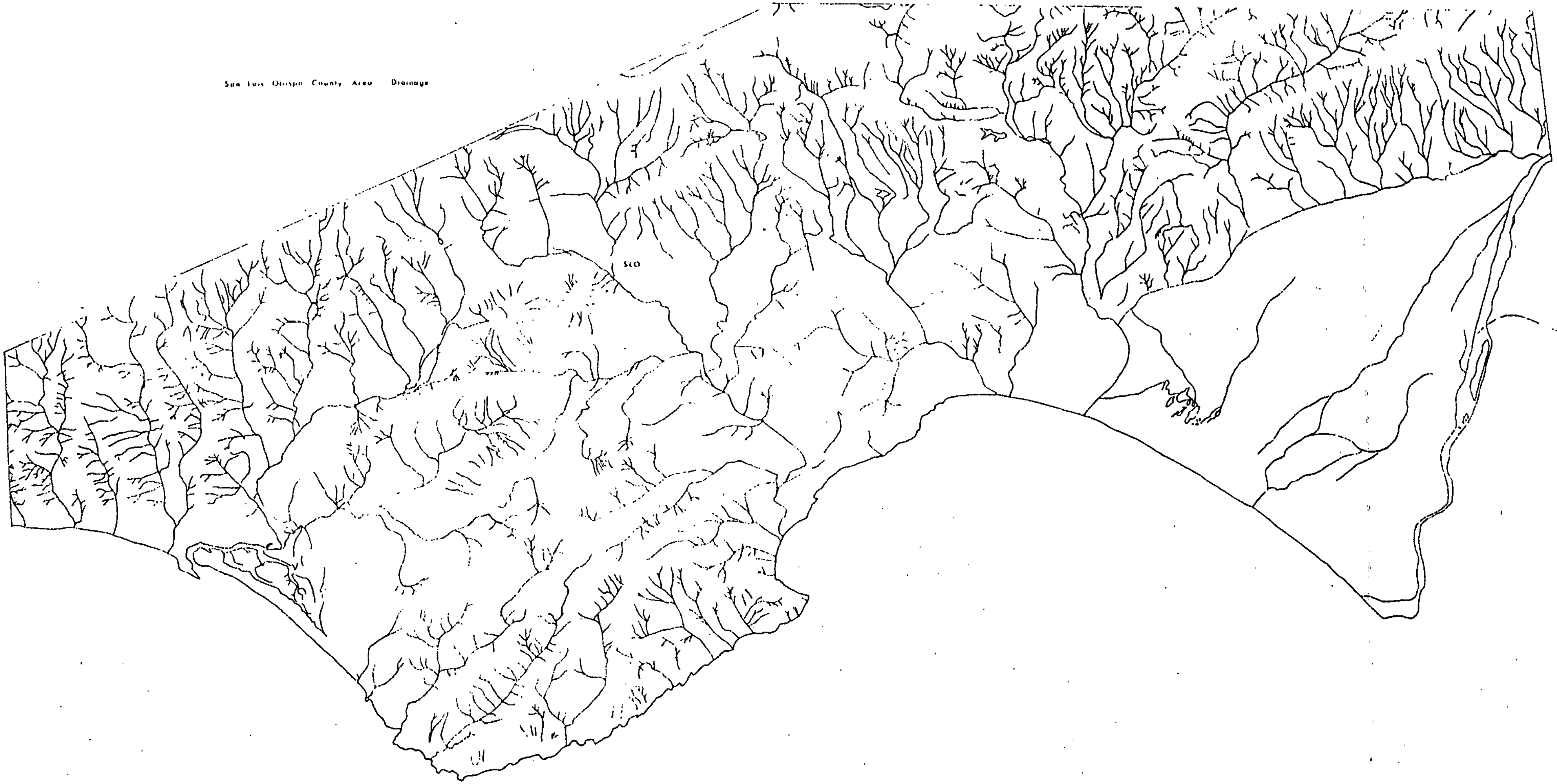


Figure 6.10. Drainage Map of San Luis Obispo County based on NASA color infrared photography, scale 1:120,000.

was extremely favorable for several reasons: (1) the level of detail in the classification systems was compatible with planning needs; (2) qualitative estimates of accuracy were within acceptable limits (±5 percent error); and (3) current information of this nature is unavailable to the counties, and is needed for environmental analysis in the planning process. It was also indicated that the California Coastal Zone Commission would need information of this type to plan for future development in the politically sensitive California Coastal Zone.

6.1.5 Goleta Valley Land Use Change

As an example of the possible applications of a Coastal Zone data base, a study of land use change in the Goleta Valley is being conducted. It illustrates the significance of a data base which is periodically updated to reflect the effects of change processes. Land and its usage are subject to change as a result of the actions of various natural and cultural processes. The geologic processes are slowest, nearly imperceptible; the biologic processes are faster, but less effective in changing land and the uses of the land. Cultural processes are rapid, and can cause large scale changes in the landscape. The impact of decisions affecting the use of land is not only confined to the specific area of change, but also has long-term regional effects. The land changes, and the region reflects the change in terms of economics, aesthetics, and productivity.

The present study is a look at the Goleta Valley area between San Roque Creek, on the East, and Dos Pueblos Creek, on the West. For the years 1961 and 1967, large scale aerial photos were combined to form

photo-mosaics. For 1971, much smaller scale photographs were used. Land use categories were mapped on a transparent mylar sheet covering the photos. The objectives for constructing the maps included: (1) determining the acreages in each major category of land use; (2) documenting significant changes in land use over the time periods involved; and, (3) inferring, if possible, the significance of land use changes to the Goleta Valley area.

Table 6.15 lists the total acreage of each major category of land use found in the Goleta Valley for the years 1961, 1967, and 1971. The total amount of agricultural acreage dropped by one-third in the 10 years between 1961 and 1971. Total row crop acreage actually rose, however. This situation may be explained if one considers that land which is "under pressure" from urban expansion does not warrant the investment necessary to start an orchard. Row crop production is more profitable in the short run, and allows the land owner to return a crop profit and sell the land at any time without substantial loss. It is land not previously used for agriculture which has accounted for the increase in row crop acreage. Tree crop areas have gone directly into residential and commercial use, as have some row crop acreages and a large number of formerly idle lands. In the 10 year period, total residential acreage has doubled and commercial-industrial acreage has tripled.

Figure 6.11 illustrates land use conditions in the Goleta Valley during 1961. Figure 6.12 shows the location and nature of specific land use category change from 1961 - 67, while Figure 6.13 shows the same type of information for the time period between 1967 and 1971. These areas

TABLE 6.15. GOLETA VALLEY LAND USE AS DERIVED THROUGH AERIAL PHOTO INTERPRETATION

	Area in Square Kilometers			
Land Use Category	1961	1967	1971	Net Change
Pasture (arpu + Arpi)	9.349	5.018	.054	- 9.295
Row Crops (Acr)	4.040	3.777	3.222	- .818
Orchard Crops (Act)	20.439	14.736	11.065	- 9.374
Other Cropland	.404	.252	.204	- .200
Single Family Residential (Rs)	12.227	22.472	23.186	+10.959
Multi-Family Residential (Rm)	.739	1.268	2.403	+ 1.664
Commercial and Industrial (C+Cc+I)	1.424	2.332	4.176	+ 2.572
Total Pasture	9.349	5.018	.054	- 9.295
Total Cropland	24.883	18.765	14.491	-10.392
Total Residential	12.966	23.740	25.589	+12.623
Total Commercial and Industrial	1.424	2.332	4.176	+ 2.572

Key to Figures 6.11 Through 6.13

Symbol	Land Use Category
a	Water bodies
b	Natural vegetation
c	Agriculture - Improved pasture
d	Idle land
e	Agriculture - Row crops
f	Agriculture - Orchard crops
g	Extractive - Petroleum
h	Public - Parks and Recreation
i	Residential - Single family
j	Residential - Multi-family
k	Public facilities - Waste disposal
l	Transportation - Airport
m	Transportation - Railroad
n	Public facilities - Education
o	Public facilities - Hospital
p	Industrial
q	Commercial - Clustered
r	Commercial
s	Public facilities - Prison
t	Agricultural - Unimproved pasture

Goleta Valley Land Use 1961

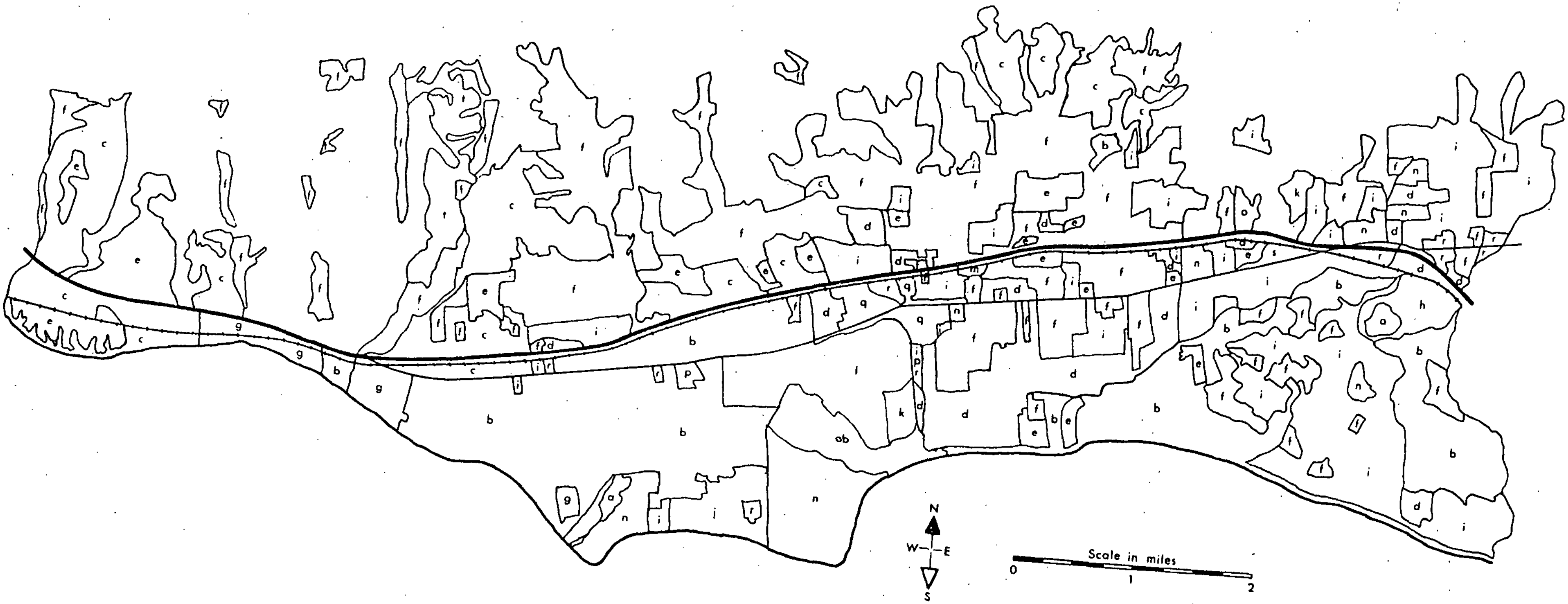


Figure 6.11. 1961 Goleta Valley Land Use based in part on an interpretation of NASA color infrared photography, scale 1:120,000.

Goleta Valley Land Use Change 1961/1967

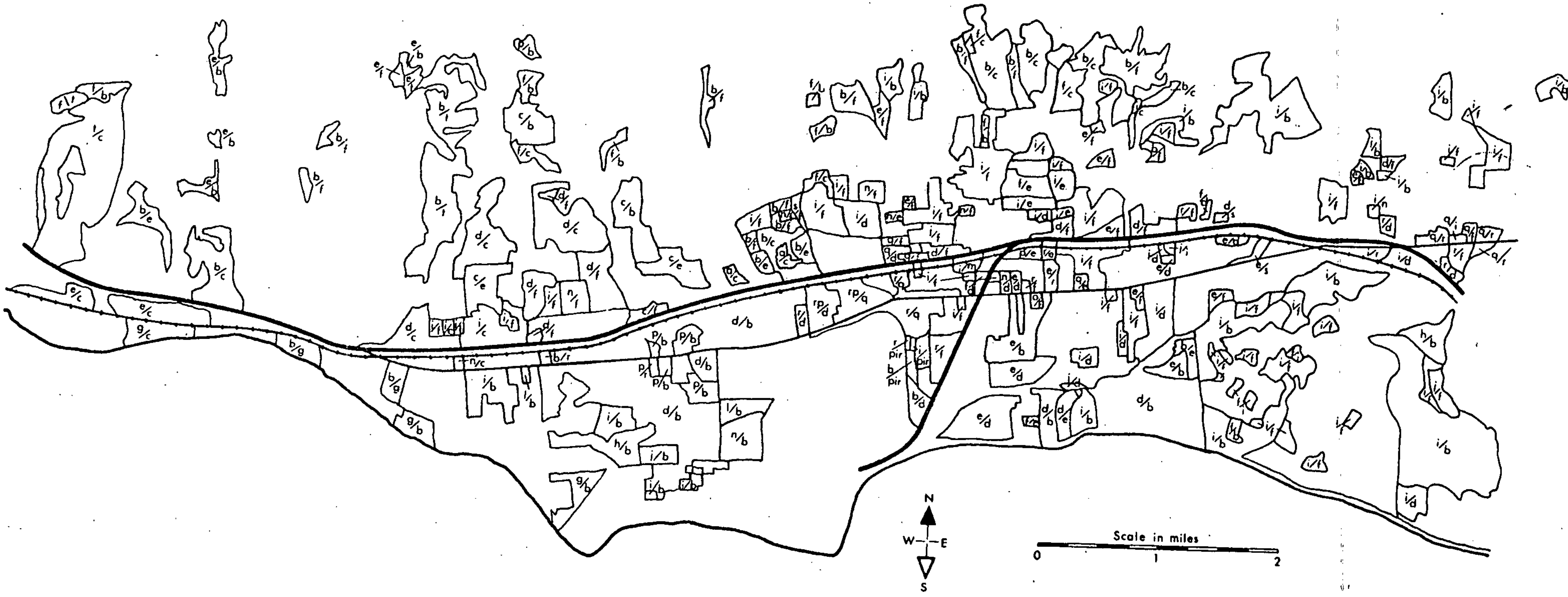


Figure 6.12. 1961/1967 Goleta Valley Land Use Change based in part on an interpretation of NASA color infrared photography, scale 1:120,000.

Goleta Valley Land Use Change 1967/1971

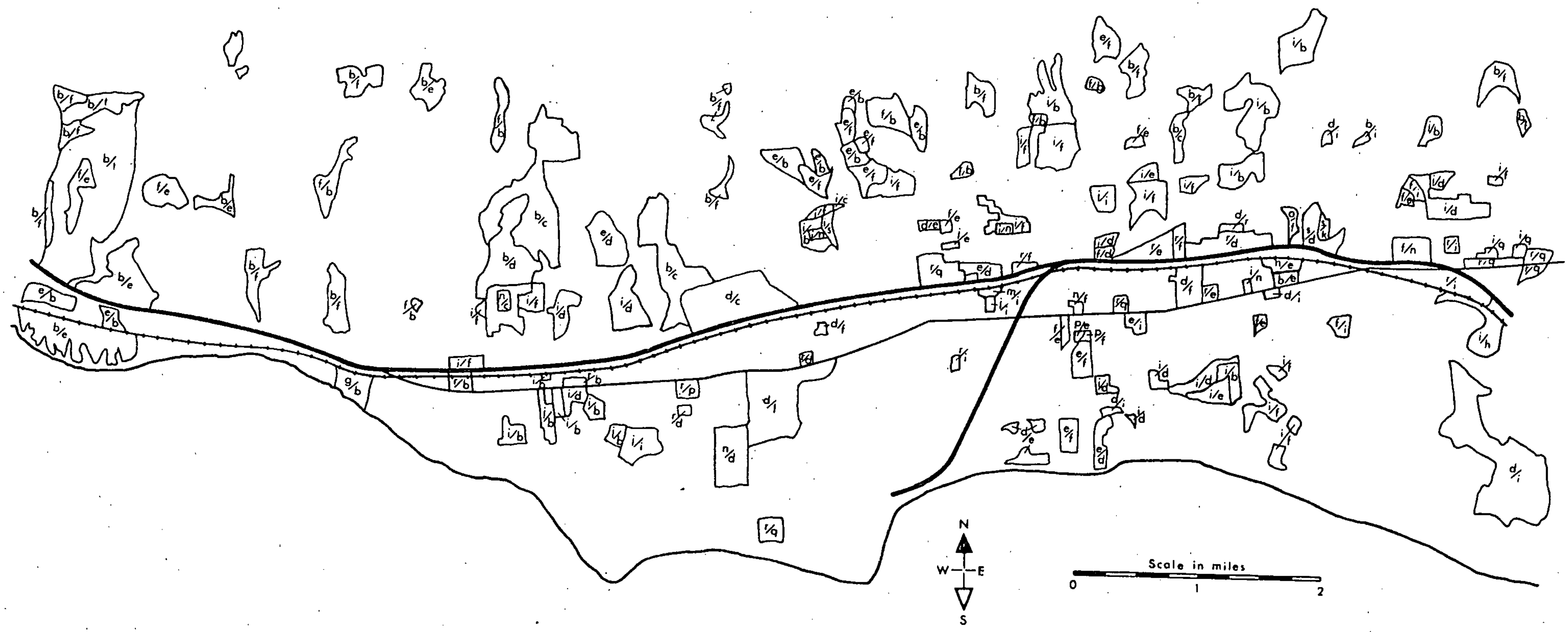


Figure 6.13. 1967/1971 Coleta Valley Land Use Change based in part on an interpretation of NASA color infrared photography, scale 1:120,000.

of change were then measured to determine quantitative estimates of the specific character and degree of change which had taken place within the Goleta Valley. The results are displayed in Table 6.16; these figures indicate the amount of land which underwent a land use category change, and the total amount of land in a specific category at a given point in time.

The data in Table 6.16 reveal significant characteristics of land use change in the Goleta Valley. Cultivated cropland (orchard and row crops) steadily declined in area. The majority of land was converted to either single family residences, multi-family residences, or commercial areas. There was some conversion of orchard into row crops and vice versa, while minor amounts of land reverted to pasturage. Pasture land (unimproved and improved) was reduced to almost negligible area by 1971; the majority of this land was converted into cultivated cropland. Single family residential land usage increased dramatically, although sizeable areas were transformed into multi-family residential and commercial usages. Multi-family residential use almost doubled every five years, with very little conversion to other uses. Commercial land followed a pattern similar to that of multi-family residential land use.

The Goleta Valley is clearly experiencing a dynamic process of urbanization. The area is changing from a rural/urban land use mix to a situation where urban land use forms are beginning to dominate the landscape. Agricultural lands (cropland and pasture) are consistently being converted to residential and commercial land uses. More importantly, the trend exhibits a pattern of progressive change. The pattern is generally

TABLE 6.16. GOLETA VALLEY LAND USE CHANGE (Km^2)

Unimproved Pasture (ARPU)

Category*	1961	1967	1971
ARPU**	1.427	1.849	0
Arpi		--	--
Acr		.080	--
Act		--	--
Rs		--	--
Rm		--	--
C		--	--
Other		1.321	1.849

Improved Pasture (ARPI)

Category*	1961	1967	1971
ARPI**	7.922	3.169	.054
Arpu		1.664	--
Acr		.502	--
Act		.397	.185
Rs		--	--
Rm		--	--
C		--	--
Other		3.195	2.984

Row Crops (ACR)

Category*	1961	1967	1971
ACR**	4.040	3.777	3.222
Arpu		--	--
Arpi		.608	--
Act		.397	.476
Rs		.265	.582
Rm		--	.026
C		.291	.237
Other			

Orchard Crops (ACT)

Category*	1961	1967	1971
ACT**	20.439	14.736	11.065
Arpu		.106	--
Arpi		.054	--
Acr		.634	.528
Rs		4.014	1.242
Rm		.211	.026
C		.423	.054
Other		1.822	3.697

Single Family Residential (RS)

Category*	1961	1967	1971
RS**	12.227	22.472	23.186
Arpu		--	--
Arpi		--	--
Acr		--	--
Act		.449	--
Rm		.132	1.162
C		.211	.582
Other		--	2.133

Multi-Family Residential (RM)

Category*	1961	1967	1971
RM**	.739	1.268	2.403
Arpu		--	--
Arpi		--	--
Acr		--	--
Act		--	--
Rs		.026	.185
C		--	--
Other		--	--

Commercial (C)

Category*	1961	1967	1971
C**	1.294	2.298	3.882
Arpu		--	--
Arpi		--	--
Acr		--	--
Act		--	--
Rs		.159	.026
Rm		--	--
Other		.132	.026

Other***

Category*	1961	1967	1971
Other**	--	--	--
Arpu		--	--
Arpi		.265	--
Acr		.449	1.373
Act		.159	.634
Rs		6.152	1.981
Rm		.211	.159
C		.449	.528

* Land Use categories into which ** categories have changed.

** Figures given for this category reflect total amount of land in that category for the given years.

*** Other represents miscellaneous land uses occupying areas too small to be treated individually.

characterized by the following sequence of conversion: (1) pasture into cropland; (2) cropland into residential or commercial uses; and, (3) single family residential use into multi-family residential or commercial uses. Land use primarily converts into progressively higher intensity forms of usage, with very little reversion to lower intensity uses occurring. Multi-family residential and commercial land uses, representing the stages of highest intensity, seldom revert to a lower intensity land use.

The change in land use discussed here occurred over a period of 10 years. But the value of remote sensing in studying the Goleta Valley is not limited to monitoring the change. Perhaps even more valuable would be to integrate remote sensing information into the Environmental Planning process for the region. Anticipation of future urban pressure and movement, of service needs, optimum open-space elements, planning hazards (i.e., areas of possible flooding and fire), and similar planning problems can be accomplished with the appropriate use of remote sensing techniques.

6.3 FUTURE PROPOSED WORK

The Geography Remote Sensing Unit at the University of California, Santa Barbara proposes to conduct several investigations for the coming fiscal year. These include: (1) completion and evaluation of the data base for the Central Coastal Zone of California; (2) continued monitoring of changes in the environment of the West Side of the San Joaquin Valley; (3) completion and evaluation of a method for inter-censal estimation of urban population size; and, (4) construction of a detailed land use map

for the Tri-County area (San Luis Obispo, Santa Barbara, and Ventura counties) of the Central Regional Zone.

Phase I of the Central Coastal Zone data base investigation, development of classification systems (land use, landforms, vegetation, etc.) and interpretation techniques, has been completed. Phase II, compilation of the data base and evaluation of the results, is in the initial stages. During the coming year, Phase II will be completed and provide a well-documented historic baseline for monitoring change in the dynamically growing Central Coastal Zone. Continued monitoring of the Central Coastal Zone will permit subsequent evaluation of the utility of remote sensing data as an information source for assessing the implications of change on both regional environmental quality and area-wide planning.

Investigations of resource parameters that are significant to the regional transformation process on the West Side of the San Joaquin Valley will be continued. The development of an agricultural region is a long-term process that is poorly understood. Remote sensing data are being, and will continue to be, used as historic documentation of the process, and as input for a subsequent model of the agricultural regionalization process. Studies focus on land use change, urban change, population growth, vegetation resources, and short-term problems that may have long-term implications (e.g., salt water intrusion in local water supplies). The studies will prove significant for future resource management and planning.

An investigation into the development of a simple and reliable method, using remote sensing data, for inter-censal estimation of urban population

size was initiated during this reporting period. A total of 20 urban sites in the Central Regional Zone are being studied. Preliminary findings indicate that the method being tested shows a great deal of promise. Research during the next year would complete the study and analysis of the 20 sites, and provide a solid statistical basis for assessing the utility of the method under investigation. The methodology will be of great significance to urban and regional planners at all governmental levels, since existing methods are totally inadequate (on a time and cost basis) for providing this now urgently needed information.

Finally, a new investigation is proposed which would concern the construction of a detailed land use map of the Tri-County area (San Luis Obispo, Santa Barbara, and Ventura counties) in the Central Regional Zone. These counties represent the most rapidly changing areas within the Central Regional Zone, and are the areas having the greatest need of accurate and up-to-date land use information. Close cooperation with local county planners will be maintained during the investigation in order to fully assess the value of this type of land use data, generated from remote sensing techniques, in the county planning process and for determining the relationship between development and maintenance of environmental quality.

N74-14012

Chapter 7

ENVIRONMENTAL MONITORING AND ASSESSMENT IN SOUTHERN CALIFORNIA USING REMOTE SENSING TECHNIQUES

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7.1 INTRODUCTION

Research progress at the University of California, Riverside, supported by the NASA "Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques," is reported herein for the year since May 1, 1972. Efforts consist of remotely sensed data applications which contribute to a better understanding of southern California's resources and environment. Early research focus was limited to assessment of the impact of the California Water Project, but the present report is indicative of the increased scope of investigations supported primarily by NASA. This report contains synopses of work being carried out at various locations by a number of researchers.

7.1.1 Significant User Applications

A number of governmental agencies (State Department of Water Resources, Bureau of Land Management, County of Riverside, County of San Bernardino) contact us at least once a week concerning studies which involve the use of NASA imagery for evaluating the impact of imported water into the environment. For example, the Department of Water Resources intends to use recent U-2 imagery in order to map

land use of all of southern California, and have continuous updating. In addition, other governmental agencies and private firms contact us periodically (State Department of Parks and Recreation, State Highway Department, Bureau of Land Reclamation, Bureau of Census, Riverside City Planning Department, Davidson Engineering, Burkland and Associates, among others) in order to use the imagery.

Updating rapid land use change is the theme of several studies included in this report. The methodologies used and especially the techniques developed are of utmost interest to county planning agencies (Riverside, San Bernardino, Imperial, Orange, Los Angeles, San Diego), and state agencies (Department of Water Resources, Department of Parks and Recreation). Studies reported herein evaluate the feasibility of coupling analyzed U-2 imagery with computer mapping techniques for the purpose of rapidly updating land use change. The immediate future will see expansion of both techniques developed and user applications. Most all of the major changes (primarily agricultural and recreational) are a direct consequence of the California Water Project's impact.

Exogenous water into coastal southern California will serve to burgeon population growth and urbanization, resulting in a greater demand being placed upon remaining local "open" spaces. Nearly all the water brought to southern California by the California Water Project is designated for municipal and industrial uses. At present, water supplies are sufficient, although projections of population made in 1950 and 1960 suggested a critical lack of water by 1980 or 2000. The water project was designed to meet such needs. However, such prophecies have a tendency to be self-fulfilling. Supplying water to an area in need encourages predicted growth.

The County of Orange, in an effort to inventory their land and design a comprehensive planning program, requested detailed vegetation/wildlife maps of the county. In a relatively short time period large scale maps were produced, using imagery from both Mission 164 and recent U-2 imagery.

The advantage of using both low and high altitude imagery for detailed mapping of montane vegetation is shown in another study. The results and techniques developed therein have been used by the National Forest Service and the State Air Resources Board.

Recreational sites along the California coast will probably experience the greatest impact from imported water. At present, coastal California receives its water supply from the Colorado River. Despite its limitations and poor quality, growth has occurred at an increasing rate, particularly in response to demands for semi-urban homes proximate to recreational areas. The demand for recreation and residences has gone hand-in-hand with the prospect of large amounts of water from northern California. The growth of recreation-oriented cities is creating an urban environment possessing peculiar economic and social characteristics. Planning for future growth stimulated by receipt of fresh water requires a detailed understanding of the characteristics of recreation cities and recognition of their growth patterns. Mission 164 and U-2 imagery allows for detailed land use mapping and predictability of growth conditions, in which respective county and state agencies are interested.

Environmental monitoring and impact assessment represents a major source area for user applications. The importation of water, especially

into desert areas, is resulting in increased pressures upon the environment. The Bureau of Land Management, State Department of Water Resources, County of Riverside, County of San Bernardino and Imperial County, in addition to smaller agencies (for example, Coachella Valley County Water District, Imperial Valley Irrigation District, State Department of Parks and Recreation), and numerous private concerns, are using imagery from Mission 164 and recent U-2 underflights along with results of the included studies in their planning programs. One study evaluates the use of vegetation as a surrogate for indicating moisture retention, a study of interest to numerous agencies.

The County of San Bernardino and the Bureau of Land Management have special interest in the increased usage of the desert for off-road-vehicle (ORV) activity. Recent U-2 imagery of the desert clearly reveals traces of random and organized ORV activity. The included studies indicate the usefulness of high altitude imagery for evaluating and, potentially, delimiting areas of such activity. It is known that both of the aforementioned bodies will use the imagery even more frequently in the future.

In the Coachella Valley the imported water is resulting in significant environmental changes; changes which will only see accelerated development. Land use changes have been dramatic. Increased recreational related development is the major focus of interest. Supplemented by additional water, many areas will be able to expand both their urban and recreational bases. Exogenous water will also have an important impact upon the locating of potential archaeological sites, a condition in which BLM has shown interest. The feasibility of using high altitude imagery in archaeological investigations is recognized.

The final study is more philosophical than applied in scope. The investigator evaluates the different role played by remote sensing techniques in two separate agencies located in Los Angeles. The results will prove valuable to any agency incorporating remote sensing techniques in their investigations.

7.2 RECENT DATA ACQUISITIONS

The successful continuation of our investigations has been greatly aided by the periodic receipt of photographic overflights of the southern California test area by NASA. Since completion of data acquisition from Mission 164, significant new imagery has been obtained from a variety of sources. The prime source of imagery has been NASA, but private contractors have flown two missions - a short, large scale flight over Cajon Pass - and an extended series of passes over selected portions of the Mojave Desert. Costs for these flights prevent sequential missions from being undertaken, and therefore, imagery received and anticipated from NASA are vitally important for continual monitoring of southern California's desert resources.

Appendix I lists all the imagery received since the termination of Mission 164 flights (April 1971). The flights listed in Appendix I include acquired 70 mm and 9 x 9" positive transparencies, flown by the U-2. All are within the southern California test site area, with selected flights concentrating on the urban parts of the Los Angeles Basin. Two other flights extend coverage beyond southern California to the Central Valley and into the San Francisco Bay area. Despite the small scale (1:450,000) of the 70 mm, it is of high quality and will be very useful as supporting data for ERTS-1 preparation for

ERTS-B and SKYLAB. All bands have good exposures and resolution useful for both rural and urban areas, although some multiband photography has been poorly copied.

The 9 x 9" transparencies represent the best imagery received to date. Not only are the color processing and resolution excellent, but the exposure settings, expecially over desert areas, allow more detailed interpretation than has previously been possible. It also opens the way for very high quality, and perhaps quantitative correlation with ERTS-1 and ERTS-B data. The RC-10 and 70 mm package contained on these U-2 missions shows definite superiority over the comparable RB-57 sensors used during Mission 164.

All ERTS-1 imagery received as of February 7, 1973 is also included in Appendix I. Images of earlier passes of the satellite were found to be wanting, by comparison, to later passes, particularly cycle 6. Primitive reproduction and enhancement techniques have allowed reasonably detained preliminary analysis of both rural and urban phenomena; cycle 6 imagery proved far better than earlier passes for interpretation of urban areas. It is anticipated that, if the quality remains somewhat consistent, some valuable information and techniques may be developed and modified through the use of ERTS data.

Earliest 70 mm negatives of the ERTS-1 imagery were found to be too dense to allow prints to be made. Like the positives, the negatives from cycle 6 are better and are quite adequate to the task. Preliminary examinations have revealed some productive uses for this sequential type data, despite the fair to poor quality of the earlier data.

7.3 INFORMATION AND APPLICATIONS ASSISTANCE

The UCR research group has consistently maintained a policy of availability and assistance with respect to the data and techniques developed and housed here. Being associated with a university, it is our function to aid progress in the education of not only students, but of people outside the university community as well. Over the past year, a substantial number of people have inquired about remote sensing, and the research conducted at UCR. There have been nearly as many types of questions and problems as people asking them. Such inquiries have come from a wide variety of businesses, institutions and governmental agencies, and have led to a consideration as to what new data and techniques might be useful. Appendix II lists the origins of these visitors and the wide array of subjects which they wished to discuss.

Clearly, our function has ranged from describing the philosophy and general uses of remote sensing and satellite platforms to assistance in detailed analysis of complex environmental problems using larger scale photography. The fact that requests come from academic, governmental and private groups reflects the importance of the research occurring and the kind of favorable public relations which come naturally with the growing association between the university and non-university researchers and users' worlds. Undoubtedly, continuing research of this sort will hasten the acceptance of the technology and will ultimately result in positive social benefits as these techniques are used in evaluating and solving environmental problems.

7.4 ACCOMPLISHMENTS

Expansion of research efforts in areal extent and methodological scope has been the emphasis of study for the NASA grant project this past year. Test site areas being monitored for impact of the California Water Project have been enlarged and new test sites have been added (Figure 7.1). Automated techniques are being developed to make the continuing monitoring of changes a feasible operation and methods of predicting land use change are being investigated. Several studies involving environmental impact which indirectly relate to the availability of water to southern California have been included to provide a complete overview within this study. The latter studies, because of budgetary limitations, have not been funded by the NASA grant, but they have utilized the imagery provided by various NASA sources. The accomplishments will be discussed in four sections.

Section 7.4.1, dealing primarily with the methodological expansion of the Geographic Information System, represents a continuing examination of the impact of the California Water Project in the Perris Plain, and the urban environment of the San Bernardino-Riverside area of southern California. In these areas monitoring and analysis of land use change has been the principle surrogate used to assess the water project's impact.

Section 7.4.2 focuses on portions of the southern California coast. Here both population and residential construction, instigated in part by the promise of exogenous water supplies threaten extant open space and environmental amenities. This coastal areal focus was in part

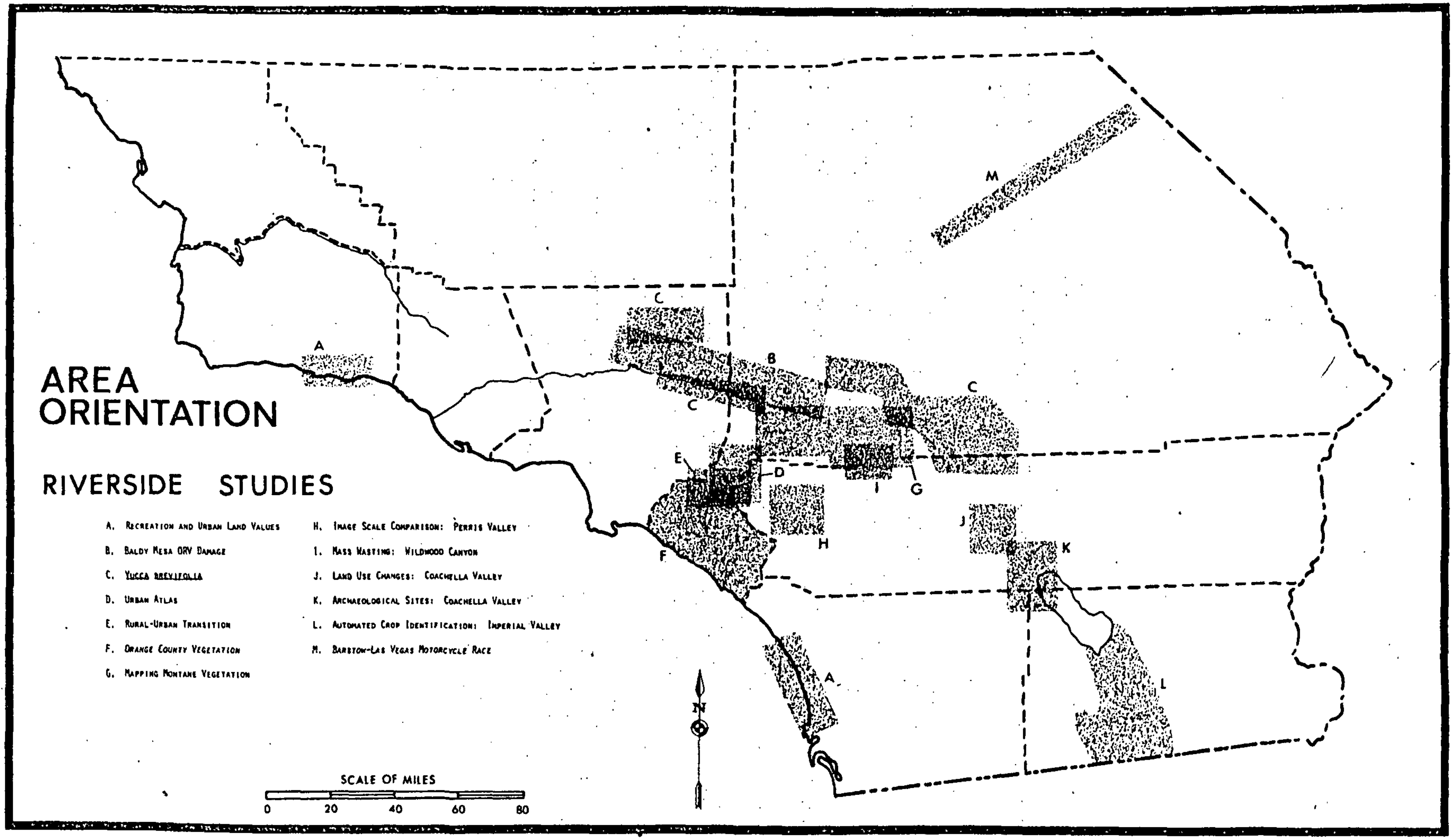


Figure 7.1. Map of southern California showing test sites as presently constituted.

established as a means of gathering data which would integrate with NASA supported ERTS-1 research efforts.

Assessment of the impact of recreational activities and urban expansion into desert environments is the theme of Section 7.4.3. Several localized studies define environmental problems now being faced and indicate potential roles remote sensing techniques might fill in assessing landscape change. Water importations into these desert areas can only serve to accentuate recreational use and residential expansion.

Because a major portion of this Department's activity consists of application assistance, we have become concerned with the problem of technology acceptance. Normally a delay exists between the date of an innovation and the date of its incorporation into applied programs. Cost is seldom the sole reason for this lack of acceptance. Usually a complex set of factors are responsible. Section 7.4.4 is a case study involving Los Angeles City and County planning agencies where researchers attempted to identify the causative factors, and thereby facilitate the future acceptance of remote sensing techniques. The results of this investigation have helped the research team at UCR to better provide potential users with imagery and techniques which best fit their needs.

7.4.1 Regional Information System

It has become quite evident that in monitoring environmental changes within a large region such as southern California, a logical method of storage and retrieval of geographic data is absolutely necessary to avoid hopeless confusion. Consequently, the acquisition

of equipment and development of methodologies for producing geographical information systems is a major subject of investigation at the UC Riverside campus. These investigations have, for several years, been supported by sources other than NASA, and more recently have been integrated with the current NASA studies. The studies in this section report on three particular phases of the total information system: (1) The Systematic Approach; (2) The Display Concept; and, (3) Detection and Prediction of Rural-Urban Change.

The systematic approach deals with the problem of abstracting data from remotely sensed imagery and transferring the data into a geographic information system. Resource managers can utilize the system output as an aid in making planning decisions.

The display concept deals with one particular type of computer display that is derived from a geographic information system. Two examples of thematic type maps are discussed, and show how the computer system can handle rapid updating of land use change in large regional areas. A system of acreage computation has now been included with the available system.

Detection and prediction of rural-urban change has been previously discussed, but the included report updates the work on this continuing project. The system being developed will use synoptic remotely sensed imagery to monitor regional rural-urban fringe areas to enable predictions to be made in advance of the transition of the change in land use from rural to urban use.

7.4.1.1 Information Systems and Resource Management - A Systematic Approach

Under NASA support, research has expanded. Using a full systems approach, researchers are continuing to develop a methodology which

would allow complete data input and information output for all resource management situations. This work, by Nichols and Brooner, was published as Technical Report T-72-3 and was jointly supported by Project THEMIS and NASA. The report, "Interfacing Remote Sensing and Automated Geographic Information Systems," utilized previous experience and addressed the entire process of combining remote sensing technology with automated geographic information systems.

The following discussion presents a scheme for utilizing remote sensing technology in an operational program for regional land use planning and land resource management program applications. The scheme utilizes remotely sensed data as one of several potential inputs to derive desired and necessary information. Several alternative approaches to the expansion and/or reduction and analysis of data using automated data handling techniques are considered. This discussion begins with the decision to utilize remotely sensed data for a land resource program, and is inclusive of the applications and considerations of analyses and products useful to variable levels of decision and policy. Within this scheme is a five-stage program development: (1) Preliminary Coordination, (2) Interpretation and Encoding, (3) Creation of Data Base Files, (4) Analysis and Products, and (5) Applications.

Stage I - Preliminary Coordination

First, one must assume that: (1) a regional land use or resource management program exists, (2) there is both a recognized need and desire for relevant environmental data, and (3) remote sensing technology has been selected as a tool to provide environmental data

relevant to the program objectives and problems. One then considers the choice of remotely sensed imaging systems to be employed. In reality, there may not be a choice of imaging systems due to costs or limited availability. For example, regional planners are often limited to existing black-and-white photography or conventional aerial photographic surveys which utilize low and medium altitude black-and-white or color negative films. Hopefully, considerations for choosing the sensor and its specifications would include application criteria, landscape parameters, and sensor parameters. An organization of preliminary coordination considerations is shown in the flow chart (Figure 7.2).

Stage II - Interpretation and Encoding

Stage II of the scheme for utilizing remotely sensed data is referred to as Interpretation and Encoding. Within this stage, the remotely sensed data are interpreted, extracted, and related to the computer data base along with various exogenous data. All data are encoded in a digital format which allows further data analysis to be made in subsequent stages of the system. Depending on the techniques employed in the various phases, the Interpretation and Encoding stage may be simple or complex, as can be seen by some of the individual considerations presented in the discussion.

The options and sources for the dissection and dissemination of environmental data confront the image interpreter with alternatives which must be decided upon in order to determine subsequent data handling means. Automated interpretation of remotely sensed images (e.g., pattern recognition) is a process which is still in the research

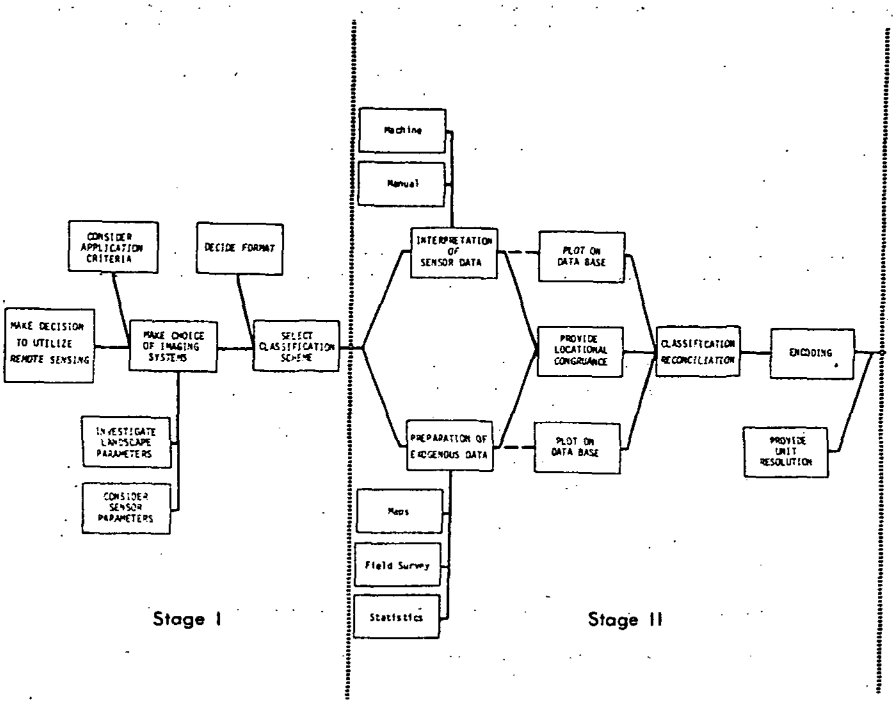


Figure 7.2a. Stages I and II of the Information System Scheme.

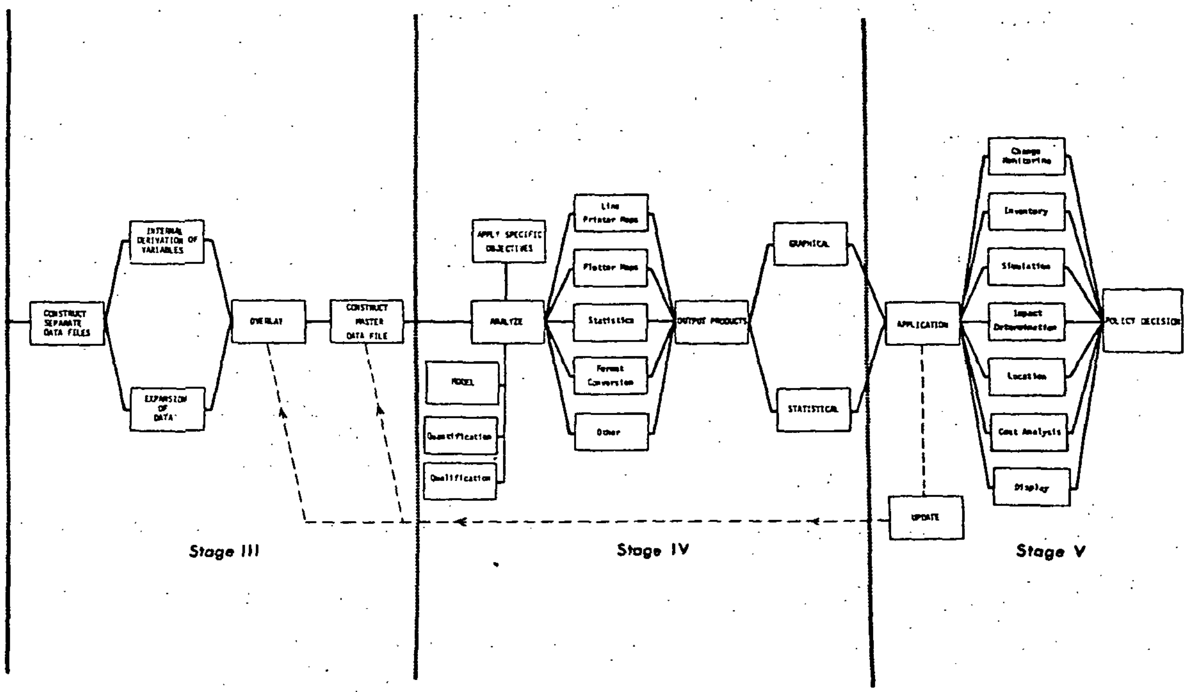


Figure 7.2b. Stages III, IV, and V of the Information System Scheme.

stage and is not extensively considered in the present discussion. With the increasing amounts of regional data being provided from platforms such as high altitude aircraft, or ERTS-type satellites, the potential for implementation and use of automated interpretation systems becomes more attractive. Manual interpretation of remotely sensed images can be transcribed by various methods. First, mapping directly onto an image overlay will necessarily capture any inherent geometric image distortions. The use of algorithms will provide for location congruence with the data base. Another alternative would be to interpret the data directly from a hand rectified grid overlay which is locationally congruent with the data base. These methods were, in fact, developed during earlier research.

Stage III - Data Base Files

In Stage II separate data files are created for each environmental phenomenon which is discretely classified and interpreted from various data sources. Furthermore, all of these data are rendered locationally congruent. In Stage III the Data Base Files are subjected to various manipulations which internally produce additional data. By deriving variables, correlating existing data, and applying various data overlays, a large number of important applicators become available to the land resource analyst.

In many cases, additional discrete environmental variables can be calculated. These would be time consuming to derive manually, but are, nevertheless, very important for applications to resource management. The derivation of these variables may be approached in two ways. The first includes programs specifically designed for a particular application.

Data inputs may be either: (1) a single variable from the data file with calculations afforded by spatial arrangement, or (2) inputs in the form of a special model utilizing empirical data not spatially correlated.

Consideration has been given to two dimensional data where the x and y coordinates specify location and the z axis provides the phenomena (event). There are cases, however, where more than one event would need to be plotted with respect to one variable. For example, air pollution would have the properties of being physically three dimensional requiring the event (e.g., oxidant concentration) to be recorded along a fourth axis. Again, this is where computer capabilities become attractive. The use of more than three axes can enable the use of data with three physical dimensions plus whatever phenomenon exists at a physical point in space.

Overlay processes combining a series of single-variable matrices with spatial location held constant have been utilized extensively. Ian McHarg's method of regional landscape analysis is a well known example. McHarg's method involves the plotting of variables on acetate rather than overlaying them physically to visualize the spatial correlations and juxtapositions. Obviously the more variables that are added, the more confusing the display becomes and eventually any empirical applications become difficult. The overlay process as used in the present system is accomplished internally within the computer. Thus, an indefinite number of phenomena can be overlaid, enabling both easy retrieval, manipulation, quantification, and modeling.

Stage IV - Analysis and Products

The next stage of the system deals with data analysis, data modeling, and generation of desired products. It is useful to remember that the integration and application of remote sensing techniques to land resource management programs is not just a problem of acquiring and interpreting remotely sensed imagery. One must also analyze the data for the purpose of providing information to land resource management programs and objectives.

Analysis of spatial comparisons provided by the integrated master data file is accomplished by selective retrieval of variables as required by specific application objectives. Each category within each variable is weighed by assigning relative values corresponding to relative desirability (positive or negative) with respect to collected environmental phenomena. The model output is generally not another variable (although it could conceivably be used as such), but rather is in the form of a series of relative assessment values. In a corridor location model, for example, soil types, geology, slopes, sun angles, and other applicable environmental phenomena, are assigned determined values in order to obtain a quantitative assessment of suitable corridor location for a particular use (i.e., highways, powerlines, etc.).

Stage V - Applications

The utilization of the described concepts affords the application of environmental data directly toward the land resource decision process, for integrating synoptic data. User options include integrating additional overlays enabling synoptic analysis, or simply

updating the master data file by obliterating obsolete data. Options for applications to management and policy decisions are governed by various goals of both data synthesis and data presentation.

A brief description of some possible applications to the land resource planning and management process follows:

1. Monitoring. This concept applies to the detection of synoptic phenomena, such as rural-urban fringe analysis, urban blight, crop morphology throughout growing seasons, levels of various environmental pollution, etc.

2. Inventory. When planning for regional growth and development, for example, resource data is often insufficient or relatively nonexistent. Remote sensing techniques provide efficient and expeditious surveys, and minimize problems of inaccessibility over large areas of difficult terrain or cover. Imagery provides vast amounts of environmental data to be recorded and interpreted, and data files allow for the storage, retrieval, and presentation of vast amounts of data useful to the resource analyst and planner.

3. Simulation. Often resource planners attempt to simulate political or economic outcomes, such as land use changes, before making various recommendations or decisions. The construction of graphical displays allows the presentation of relevant information to the participants in the "gaming" process.

4. Impact. Planners often must ask themselves "What if we do... and what if we don't...?" With the concepts and systems described, assessments of relative "impact" may be generated to enable planners, first, to better answer such questions, and second, to provide alternative comparisons.

5. Location. Once the decision is made regarding, for example, the development of a certain activity, the question becomes one of optimum location. Quantitative assessment of environmental, political and economic parameters may be used to narrow the choice to several alternate locations.

6. Cost. When economic inputs must be considered, assessments of cost and cost alternatives may be easily computed using the proposed system.

7. Displays. Communication between planners and policy makers is often inhibited due to information formats that are difficult to interpret. Flexibility of display modes allowed by this system should ease communications.

Historically and presently, inventory, planning, and management of land resources is an extremely variable process among regional population concentrations and frequently non-existent or minimal in smaller populations. Land use maps, for example, are costly to produce due to dependence on traditional ground survey methods, and once completed, are of limited historical value. The value of current and dynamic regional land use data and maps is their potential for "synoptic use in observing economic patterns (and resources) rearranging themselves."

There is growing agreement that the "state-of-the-art" of remote sensing has advanced to the point of being very useful for the detection of environmental resource data. The need for more, better, and timely land use data for planning is obivous. Also present is the need to evaluate and manage our resources. Various remote sensing techniques are more applicable than any other method of survey for numerous

environmental phenomena which must prerequisite resource management decisions. *The realizations of automated systems to integrate data* derived through remote sensing techniques with multiple sources of exogenous data, and the ability to manipulate, store, retrieve, display, and update the resulting information, will enable the transfer of remote sensing applications and technology into the effective operations of resource management.

7.4.1.2 Computer Prepared Thematic (Qualitative) Maps

The core of a geographic information system is the ability to rapidly produce a thematic or qualitative map of analyzed or correlated data. The efficiency of the display produced by the computer depends on the ability to change scale, update data, generalize map data, and most important - produce a map of large areal extent without having to mosaic individual maps. Research at the Riverside Campus has utilized several computer mapping systems as an integral part of our NASA study grant. Previous reports contained discussions of two systems - grid matrix, and polygon overlay. Study this past year has concentrated on a third system - CALFORM - which is most useful in displaying current and changing land use. The CALFORM program was originally developed at Harvard University, Laboratory for Computer Graphics, but it has been greatly modified at UCR to enlarge area capability as well as provide acreage calculation summaries. The CALFORM display technique is included in two current studies which serve as examples of two of the capabilities of the program.

The first of these discusses an ongoing study involving land use mapping of a large regional area. The display for this area indicates the detailed land use that can be provided by the CALFORM program for

an area as large as 40,000 acres. In addition, the CALFORM program also provides acreage summaries for each land use classification. The acreage summaries are not limited to the generalized land uses displayed on the map, but will provide detailed summarization limited only by the scale to which the data has been coded.

The second study focuses on monitoring land use change resulting from the impact of Lake Perris (California Water Project). In this area the land use is predominately agricultural and subject to rapid seasonal variations. The CALFORM display has proved to be an excellent program to handle rapidly changing land use.

7.4.1.2.1 Regional Land Use Mapping and Data Compilation

Modification of the CALFORM computer mapping program, to map a large area (40,000 acres) of detailed land use with one continuous map plot, is making the monitoring of change in a large region a feasible task. The ongoing Urban-Rural Land Use program encompassing the Inland Valley of the Los Angeles Basin (Riverside-San Bernardino-Ontario, Figure 7.1) serves as the test site for the computer assisted Regional Land Use Mapping Study.

Five CALFORM type maps of the region have been produced and are in the process of being updated from NASA U-2 type imagery. The base land use data employs 52 second level categories chosen from the Department of Housing and Urban Development (HUD) land use classification system. The base data was derived from Mission 164 imagery at a scale of 1:120,000. The number of land use categories detected using high altitude imagery exceeds the second level classifications adopted by the Inter-Agency Steering Committee in their "Land Use Classification

System for Use With Remote Sensor Data" (Geological Survey Circular 671). It would thus appear that the resolution of the NASA U-2 high altitude imagery taken with the RC-10 camera will permit detection of many third level classifications that the committee suggested could only be obtained from smaller scale imagery. Figure 7.3 is a photo mosaic of the Inland Valley Region taken by the NASA U-2 on July 11, 1972. The original scale 9 x 9" CIR transparencies permits the segregation of most residential areas into third level classifications.

Five extant computer maps of the Inland Valley each use the corresponding USGS 7.5 minute (1:24,000) topographic quad sheet as a base map. Since the base map scale is larger than the 1:120,000/130,000 imagery, it easily provides the necessary work space for preparing map data for encoding to computer data format. The largest number of polygons (individual land use areas, i.e., public school grounds) on the current maps is 331. However, the present CALFORM program will permit 2,500 polygons to be outlined on a single map. The polygon limit does not necessarily restrict the size of the final single plot map that can be produced. The single plot size of a regional map is only restricted by the map scale and plotter bed size. Figure 7.4 is a map mosaic that was not produced by a single computer plot, but represents five separate quad sheet overlays. Scale reduction from the origional 1:24,000 base was accomplished by both computer and photographic means.

The map mosaic represents land uses within two counties (Riverside and San Bernardino), a combination seldom seen in this region. The analytical capability of the map provides the user with the ability to consider regional scale morphology and may give planners a perspective

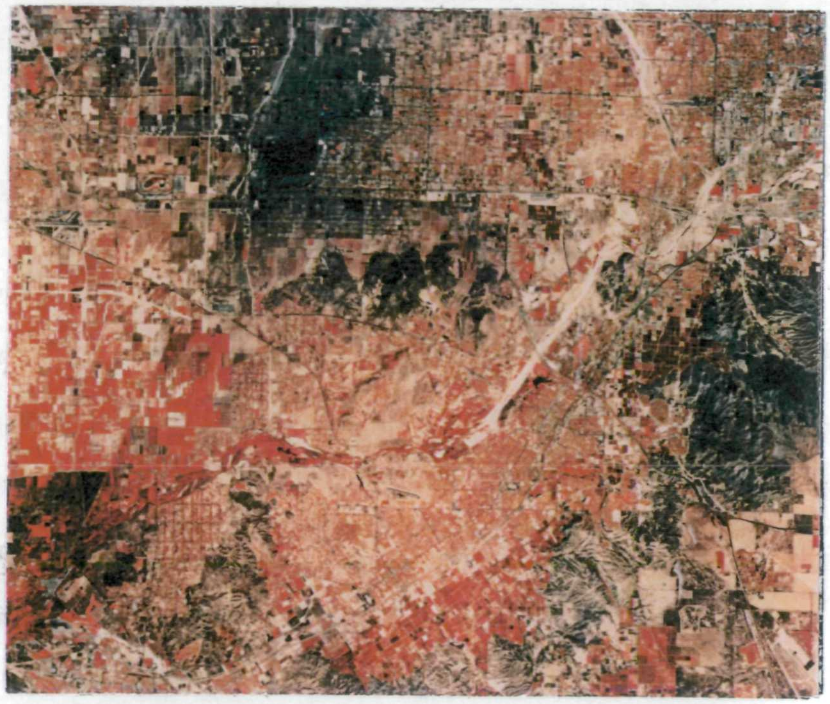


Figure 7.3. U-2 photo mosaic; centered on Riverside, California.

Figure 7.4. Land use map of Riverside-San Bernardino test area.

they now lack. One obvious conclusion from a cursory examination of the map mosaic is that the freeways did indeed come after the cities were built. The dark commercial strip areas reveal the original main arterial streets. The upper two quad maps show the Interstate 10 Freeway bisecting the maps in an east-west direction and little commercial activity can be detected along the freeway. The commercial strip along the top of the map paralleling the freeway represents the development of the old transcontinental Highway 66 through the cities of Fontana and Rialto.

The agricultural land use patterns indicate that there are still some "green" belts around most of the cities, but residential incursions into the green belts can be detected around each growth center. In the lower center quad only two service-type land use areas along the State 91 Freeway (Cal Baptist College and Sherman Indian Institute) remain in the old separation between the original area of Riverside and Arlington which now form a single city. Careful analysis of the map mosaic will show many other previously unrecognized relationships.

Another sub-routine modifying the CALFORM computer mapping program has produced a most useful statistical summary. Acreage calculations can now be produced for the entire regional map. At present the smallest unit area of the summary is the base quad sheet. The detail of the summary is limited by the scale to which land use has been encoded to computer compatible format. For clarity of presentation the 52 categories of land use which were interpreted from the high altitude imagery have been generalized on the map display to eight first level land use classifications. Table 7.1 summarizes the acreages for each of the classifications within each of the five quad sheets.

TABLE 7.1

URBAN-RURAL REGIONAL LAND USE SUMMARY

Riverside-San Bernardino-Ontario

(Spring 1971)

CODE	CLASSIFICATION	NORTH CORONA		WEST RIVERSIDE		EAST RIVERSIDE		SOUTH SAN BERNARDINO		FONTANA		TOTAL	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
10	Living Area	7,034	(17.8)	11,462	(29.0)	4,593	(11.7)	12,114	(30.7)	13,717	(34.8)	48,920	(24.8)
20	Industrial	170	(0.4)	441	(1.1)	469	(1.2)	1,220	(3.1)	883	(2.2)	3,183	(1.6)
40	Transportation and Utilities	2,582	(6.5)	1,248	(3.2)	534	(1.4)	1,815	(4.6)	503	(1.3)	6,682	(3.4)
50	Commercial	474	(1.2)	1,013	(2.6)	612	(1.6)	1,981	(5.0)	555	(1.4)	4,635	(2.4)
60	Services	365	(0.9)	1,409	(3.6)	5,680	(14.4)	1,420	(3.6)	609	(1.5)	9,483	(4.8)
70	Recreational & Cultural	552	(1.4)	909	(2.3)	1,028	(2.6)	640	(1.6)	332	(0.8)	3,461	(1.8)
80	Resources (Agricultural)	16,908	(42.9)	11,354	(28.7)	10,101	(25.7)	12,074	(30.6)	17,347	(44.0)	67,784	(34.4)
90	Undeveloped	11,367	(28.8)	11,677	(29.6)	16,373	(41.6)	8,207	(20.8)	5,442	(13.8)	53,066	(26.9)
		39,452		39,513		39,390		39,471		39,388		197,214	

Reading from left to right on the map mosaic (Figure 7.4), the lower quad sheets are North Corona, West Riverside, and East Riverside. The upper quads are Fontana and South San Bernardino. Statistical totals for 197,214 acres included for the map mosaic of regional land use provides another analytical tool. The most developed quad area is Fontana with the Jurupa Hills to the south being the only undeveloped area. The 34.8 percent area is greater than the highly urbanized South San Bernardino quad. Socio-economic characteristics of the residential areas cannot be determined from the land use maps developed at this scale. A complete geographic information system would therefore have to include census data. However, the presence of the Kaiser Steel Plant (represented by the large industrial area to the west center of the Fontana quad) would suggest that the majority of the residential areas of the Fontana quad contain blue collar families. A deficiency in both the land use map and the statistical summaries listed only by first level classification is that the true function of the area in the North Corona quad is not revealed. The large agricultural area is undefined in both the map and the statistics. The statistics would have to be listed to the third level classification to see that nearly 90 percent of the agricultural area is in dairy farming. The data is available from examination of the original scale NASA U-2 imagery on which each dairy lot and associated alfalfa field can be detected.

The brief analysis above indicates that considerable study of the products of our regional computer mapping techniques needs to be accomplished. However, the present state-of-the-art provides a significant tool for land planners and resource managers. Acquisition of a four

pen plotter this coming year will provide a capability to produce four color maps with second level classification detail being displayed. Updating techniques will be developed. The ability to produce the CALFORM display at any scale will permit an outline map to be constructed to NASA U-2 image scale (resulting in rapid updating).

7.4.1.2.2 Updating Rapid Land Use Changes

The most challenging test of rapid updating procedures for land use maps is provided by agricultural areas. Southern California with its year-round growing season provides an exceptional example of such a challenge. The CALFORM map display system provides a most unique system for updating agricultural crop data. The ongoing land use study around the new Lake Perris (terminal reservoir of the California Water Project) provides an excellent study site for the updating technique.

Analysis of the Perris-Moreno Valley area of Riverside County has been detailed in previous reports. The example shown in Figure 7.5 indicates the great seasonal variation found in most agricultural areas. However, the climate of the area still permits many irrigated vegetable crops to be produced in late fall and mid-winter. These are indicated on the December 9 map. The early spring map contains many grain fields that produce through dry farming techniques. It is the change from dry farming to irrigated farming that is being closely watched within the Perris-Moreno area. The significance in the system is that once a base map has been encoded into the computer it takes only one to two hours to update the display. Image interpretation for the December 9 image required only 30 minutes and the encoding another 30 minutes. Figure 7.6 is the NASA U-2 July 11, 1972 image of the same area. The evidence of dry farming can be seen even in this black-and-white

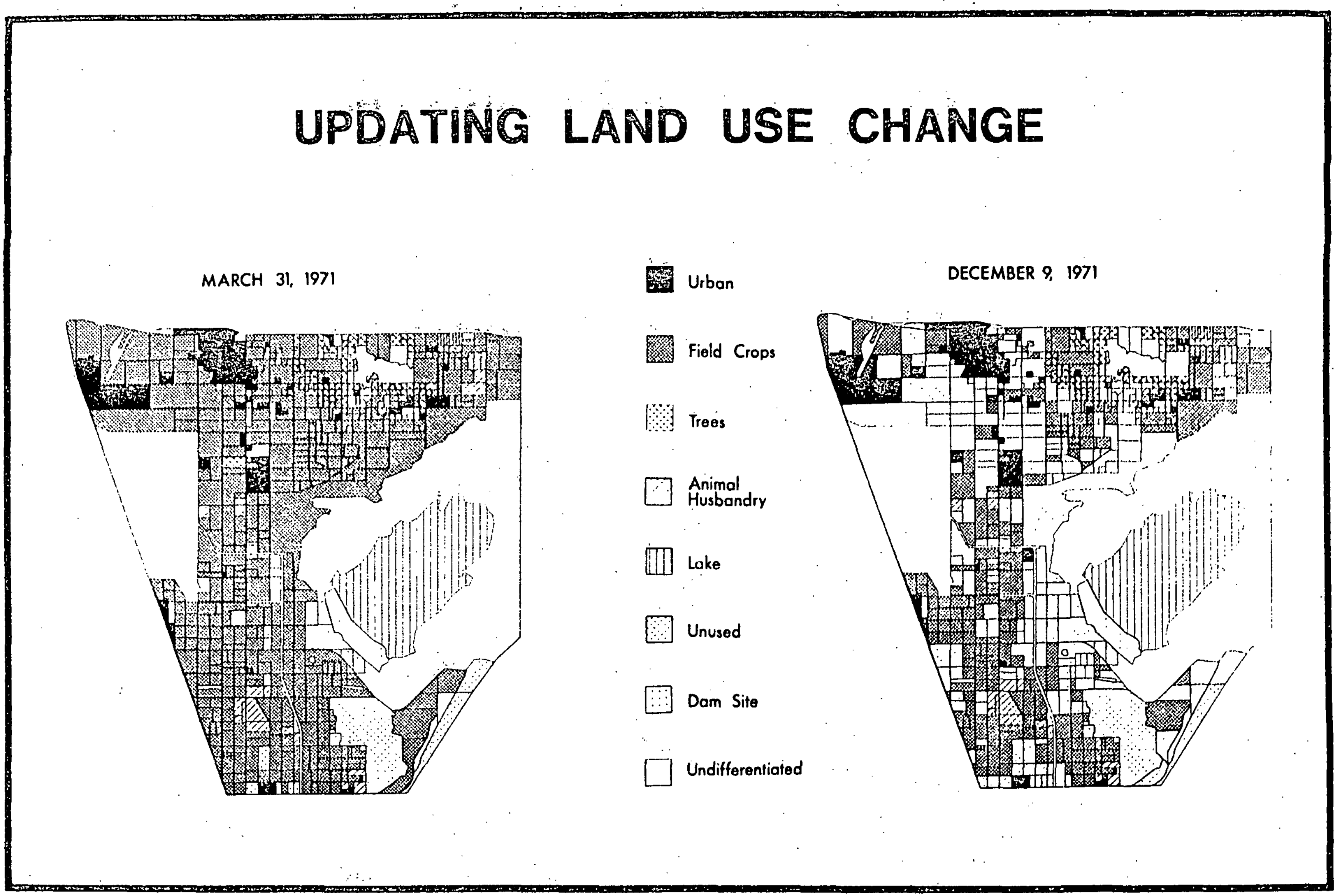


Figure 7.5. Maps showing conditions in a representational test site as of March 31, 1971 and December 9, 1971. Note substantial changes in land use, as discussed in the text.

Figure 7.6. U-2 photo (1:131,000) July 11, 1972 of the Perris-Moreno Valley. Dark fields represent irrigated crops. The predominance of dry farming indicates little crop production during this season.

image from the large number of bare fields. The grain crops around the lake area failed to mature because 1971 was the driest year in recorded weather history (no rain fell after December 15, 1971).

In the northern part of the plain around March Air Force Base and along the transportation artery provided by State Highway 60, residential subdivisions (both single and multiple family dwellings) are being constructed on land previously dedicated to agriculture. This is not a new trend which owes its existence to the inception of the California State Water Project, although information concerning Lake Perris and surrounding state recreation facilities have had some effect as a stimulus to growth.

Throughout the Perris Block of the Peninsular Ranges (roughly the area between the Santa Ana and San Jacinto Mountain Ranges from Riverside to Rancho California), recreational oriented land uses have replaced agriculture at a limited number of sites. Most of these are, according to Clawson and Kenetsh (Economics of Outdoor Recreation, 1967), intermediate facilities which are neither population nor resource oriented. Although some of these sites are designed as centers of second or recreational residences (a typical occurrence in the northern Coachella Valley) most often the developments serve as recreation vehicle campgrounds, mobile home sites, or as centers for day uses. There is no doubt that proposed recreational developments associated with the California Water Project are partially responsible for the development of these uses. Hopefully, research during the next years will provide more conclusive results concerning these already identified trends. May 18, 1973 will see the arrival of northern California water in Lake Perris and it is anticipated much change will develop this coming year.

The techniques developed within the Perris Valley agricultural area have been utilized in an extensive associated NASA study in the Imperial Valley. Some 8,000 plus agricultural fields are being monitored on an 18-day ERTS-1 cycle to develop a system for computer assisted crop identification. The data is providing information that can be used to provide a monthly prediction of irrigation water demands. The prediction techniques will be utilized in current studies in the Perris Valley to determine if water demands within a mixed dry-irrigated farming area can be predicted with equal ability.

7.4.1.3 Monitoring Rural-Urban Transition

The logical method of interpreting and analyzing remotely sensed data outlined in the previously described systems approach is not without its problems. One such problem area is encountered in the interpretation of the factors involved within rural-urban fringe zones of transition. The environmental changes taking place in this zonal area are complimented by human interference. A study is currently being conducted to determine if in fact there is some logic, and hence, predictability in the way man effects change in the Southern California rural-urban fringe area. The investigation concerns the use of synoptic remotely-sensed imagery for monitoring regional change. This study in urban dynamics has both practical and theoretical values. Its practical value is to urban and regional planners who will be able to foresee transition problems before they occur, and thus, can take corrective action and then monitor the further developments. The theoretical value is to students of urban morphology who will be able to observe the processes of rural to urban transition and land use succession.

The study began two years ago with a slightly different objective. Synoptic imagery was to be used in examining freeway impacts on agricultural land use, the expectation being that agricultural uses would change as anticipation of the freeway rose, as the actual construction proceeded, and as the route finally was completed. It was expected that labor and capital inputs to land would be intensified to raise productivity in keeping with higher carrying costs for rural land now taxed at urban rates. Instead, the phenomenon of factor disinvestment, or the minimization of factor inputs to land was observed. Sinclair described this phenomenon in a recent journal article, "Von Thünen and Urban Sprawl," (Annals of the Association of American Geographers, Vol. 57, 1967), but he did not test it empirically, nor did the few other investigators who observed it analyze its causes. Examples of disinvestment patterns and their origins are yet unclear. Rather than a progressively more intensive production-factor-use-agriculture approaching an urban fringe in accord with the 150 year-old Von Thünen theory (which suggests that land rent appreciates from locational utility, and that land uses are ordered by their ability to pay these rents and the transportation costs), the proximity clouds the long-run planning horizon and forces fringe land owners to adopt short-run plans. This is particularly true in dynamic situations, e.g., when a major transportational route is constructed. Production factor use is minimized because labor earns higher returns in the city; capital has higher returns in land speculation or in investments other than farming. Land, as a consequence, is farmed without much capital or labor input, and such extensive uses as grazing, and the farming of barley and other field crops prevail in areas "clouded" by urban proximity.

The original study area was composed of the Walnut Valley, in eastern Los Angeles County. Land use changed within agriculture in a number of ways before urban land use (residential, industrial, institutional, etc.) succeeded. Five types of decisions made by land owners were identified as:

1. Intensification: the increase in factor use as in the replanting of citrus, the enlargement of a dairy, or the planting of row crops in place of field crops.

2. Direct conversion: the change of productive agriculture to urban use, as in the replacement of productive citrus groves by subdivision.

3. Succession: the following of low-productivity agriculture by urban use, as urban barley fields or deteriorated citrus is followed by a subdivision.

4. Disinvestment in Lieu: the following of productive agriculture by a less productive agriculture, as when citrus is replaced by barley farming.

5. Disinvestment: the allowing of agricultural uses to deteriorate _in situ_.

Land owners adopted these strategies in different proportions depending on the urgency with which they perceived conditions for land use change. Owners tended to adopt land sale enhancement strategies (disinvestment in lieu) in periods of "booming" growth and disinvestment strategies when sales (lending rates, financing availability, etc.) were off. The intensification of agricultural land use was thus a much less important decision than expected. In broad terms, the

expanding Los Angeles fringe through Walnut Valley triggered land use change to urban uses and agricultural decline through disinvestment stages.

Research concerning the preparation and transformation of rural land to urban uses is continuing at the Riverside campus. Theoretical statements are, at best, hypothetical on the basis of even intimate observations at a sample location. In order to substantiate previous statements, the hypothesis of disintensification of agricultural land use immediately prior to urbanization will be tested in four other areas. Tentatively these areas are: (1) The Dairy Valley area of Cypress in Los Angeles County; (2) the Placentia area of Orange County; (3) an area of the East San Gabriel Valley in Los Angeles County; and, (4) either the Dominquez Hills or Venice area of Los Angeles County.

The above locations each exhibit different agricultural landscapes. Hopefully this additional research will not only lend credence to the hypothesis under consideration, but will also establish what other types of agricultural land uses undergo factor input reduction before giving way to urbanization.

During the past year research has concentrated on typical agricultural forms of southern California which, in comparison with farming nationwide, tend to be highly capitalized, intensive and specialized. In the citrus industry emphasis is placed on the manner in which each form evolves under urban pressure, particularly on remotely sensed evidence of change that can be supported by ground truth data (e.g., production data, both inputs and outputs). A portion of Orange

County, California, served as a test site (Site 2 above). This region, bounded by the Santa Ana River on the south, the Orange Freeway on the east, and the Puente Hills on the east and north, contains two incorporated communities, Placentia and Yorba Linda, and substantial evidence of urban encroachment into agriculture. Other reasons were important in the site selection: (1) the off-center location of the region and its delayed urbanization (ample photo coverage was better assured); (2) the excellence of soil and citrus production tends not only to deter urbanization but make its impact more dramatic; and (3) the abundance of related "ground truth" data.

Urbanization began rapidly in the region after 1960, prompted by local capital projects, and has fluctuated with the vagaries of the building industry. Idled land and urban land uses had almost totally replaced the citrus landscape by 1972. The decline of citrus cannot be attributed solely to urbanization, however, and the research was extended to provide the explanatory factors necessary to provide a complete setting for citrus disinvestment. Economic health was generally poor in the industry for some time. Urbanization became only a fortuitous occurrence that enabled individual growers to recover past losses in large-scale land appreciation that followed growth of southern California's population. Urban impacts were felt in many sectors: (1) costs of production rose; and (2) difficulties of production rose (infrastructure breaking down). As a result growers became sorted in terms of their propensity to withstand these impacts and their outlooks changed. Higbee (1969) classified on an urban fringe in four categories: (1) part-time farmers; (2) under-capitalized

farmers; (3) serious farmers; and (4) investor farmers. All were represented in citrus districts, historically and presently, with only their relative numbers changing. Part-time farming was the original basis under which the industry spread on small farms. Labor efficiency and economies of scale were difficult to achieve at the early stage of the industry, but labor was disinclined to shift to other activities. (Eventually, growers took on other employment as opportunities were presented.) Marginality resulted from a lack of a sound knowledge concerning the raising of sub-tropical fruits and a difficulty in optimizing physical constraints (soil, exposure, micro-climate). "Boom" years attracted producers whose numbers were adjusted by recurring periods of "bust." Citrus acreage and farm numbers, however, represented heavy fixed investments which caused contraction of the industry to come slowly. Serious growers deserve special attention in subsequent paragraphs. Investor farmers, aside from modern "corporate" and "tax-shelter" farms, were important in a transition period when groves were purchased, farmed, and operated by managers and phased in keeping with an overall development scheme.

By monitoring the fringe one observes various planning strategies. Some of these can be identified with a specific type of grower. These decision patterns can be divided into three types: (1) groves with good care; (2) groves with minimum care; and (3) abandoned groves.

Every grower bases decisions on grove potential. This includes soil, production costs, and management ability factors, and their availability; or, in other words, physical, economic, and social considerations. The actual production process finds these factors

increasingly more mobile with their scarcity; i.e., management labor is a more mobile input of greater scarcity than an opportune economic situation, etc.

Soil had much to do with a grove's initial prospects. A poor grove was worth its cost until recently; a good grove was dear at any price at any time. Coupled with efficient and competent management, sites with good soil produced incomes which could offset rising production costs for considerable time. As the citrus landscape evolved, growers on poor soils who always had poor production and were most marginal tended to leave the industry first. The actual decision depended much on existing conditions; e.g., the availability of alternative uses for the land, and the change in any of the "urban" pressure factors: rising taxes, water, and labor costs, and problems associated with people that make farming difficult (pilferage, vandalism, complaints, air pollution). Depending on the extent of this assemblage of influences, a grower either abandoned the grove (ceased irrigation) or adopted a minimum care program (cut back in spraying, replacement, trimming). The choice among decisions can best be explained by examining the reasons for maintaining good cultural care.

Good groves, while they become increasingly uneconomic through time, were maintained so that output could offset fixed costs of production (taxes, depreciation) and perhaps pay a profit in occasional good years. The following table illustrates why.

TABLE 7.2

TWENTY-YEAR COMPARISON OF PRODUCTION COST

(per acre)

Yield	500 boxes		400 boxes		
Price	$2.00/box		$1.25/box		
Income			$1,000.00		$500.00
Costs					
Taxes		$60.00		$500.00	
Water		15.00		75.00	
Grove care*		60.00		140.00	
Pest Control		60.00		100.00	
Miscellaneous		15.00		30.00	
Total			$ 210.00		$845.00
Net Profit			$ 790.00		-$345.00

*Includes irrigation labor, weed control, rodent control, extra care for replants, management.

Source: George Jacobsen, Placentia, California, grove manager.

Yields declined over the past twenty years due to tree aging and air pollution. Prices declined due largely to overproduction. Production costs, on the other hand, rose considerably, particularly costs associated with urbanization (taxes, up 833%; water costs, up 600%; labor costs, up 300% [estimated]). By producing, a grower reduced the potential loss he might incur. For example, taxes he cannot escape whether or not he continues raising oranges. Provided the grove is sound, an additional $345.00 investment in cultural care provides $500.00 in income. While he does not make money on the crop, he reduces his potential loss by $155.00 by gambling $345.00. Alternatives are less attractive: razing the orchard and planting a more remunerative crop for interim use costs $600-700 per acre for tree clearance and up to $2,500 per acre improvement costs for specialized crops, such

as strawberries, which could return a profit. Such alternatives were feasible provided the soil was suitable, skills were present, and the farmers were so motivated. In general, the industrial zoning of groves on sandy soils of the Santa Ana River floodplain (eminently suited for strawberries) were unlikely to become urbanized within a short time and lent themselves to this alternative. Over most of the region, however, it was not practical.

Minimum care could be practiced by reducing cultural care expenses dollar-for-dollar with reduced income. If loss in income exceeded savings from reduced production costs, it would not pay the grower to adopt minimum care; if loss in income was less than the savings, minimum care provided a viable alternative investment strategy. What few growers knew at the outset was that minimum care had a cumulative effect: while quantity and quality of output did not decline appreciably in the first year, subsequent crops were increasingly poorer. If grove quality was insufficient to produce crops equal in value to production costs (the variable portion) <u>minus</u> taxes (a fixed cost), a grower would likely abandon production.

The 1972 citrus landscape illustrates all three strategies. In general, they are associated with types of farmers according to Higbee (1967), and they also correspond with decision types distinguished earlier (Goehring, 1971) (Table 7.3).

TABLE 7.3

DECISION TYPES/STRATEGIES

Farmer Types	Farmer Strategies	
(Higbee, 1967)	(Placentia-Yorba Linda, 1972)	(Goehring, 1971)
1. Part-time farmers	1. Minimum care until eventual abandonment	1. Disinvestment followed by a succession of urban use
2. Under-capitalized farmers	2. Abandonment	2. Disinvestment followed by a succession of urban use
3. Serious farmers	3. Good care until the grove is sold; possible conversion to higher paying crop	3. Direct conversion to urban use; intensification within agriculture
4. Investor farmers	4. Minimum care; often abandonment; possible clearing with/without replanting a higher yielding crop	4. Disinvestment; disinvestment in lieu; possible intensification

The emphasis on good management and efficient production on good soils has led to grove management as a field of labor specialization. This type of "serious farmer" can often be associated with investment situations; e.g., future school sites, power line rights-of-way, mineral reserves. Leases for long terms (20 years or more) with some assurance of permanency and lower tax rates permit continued production by managers operating as individual farmers. Here, it is the public (school sites), the utility company, or the mining industry who has invested and obtains interim income from lands planned for other uses. Grove care practices are good with considerable consistency irrespective of disinvestment or abandonment surrounding these institutional "islands."

Periodic air photo coverage permits monitoring changing conditions within the grove that are paralleled by investment strategies employed by grove owners. As such, periodic observations of grove conditions lead to rapid identification of parcels likely to become urban and the time in which they might be converted. Having such information is an obvious benefit to planners concerned with the evolving urban landscape. Similar indicators may be able to be established for inner-urban space as well. Most urban planning is done with data derived from varied sources, largely secondary in nature, due to the absence of a data source specifically oriented to planning. Most secondary data are out-of-date once in the hands of the user-planner and the quality of decision making derived from these data thus becomes deteriorated. Planning in light of environmental considerations, an approach currently ascending in importance, requires identification of qualitative parameters in ways that can be quantified. Remote sensing tools provide ways of obtaining consensuses on quality (e.g., grove condition) and monitoring the way quality changes over time by the synoptic facility of inexpensive aerial photography. If planners would incorporate such data in a manner that identifies the processes behind each change in the landscape, their decisions not only would be improved but their abilities to model the interrelationships within the physical-economic-social environment would be substantially increased to the benefit of projections and policy recommendations for the future. Planning has tools to improve the quality of life in the future whose effectiveness is reduced by lacking an understanding of how tools should be applied. Research tools, such as

remote sensing, offer better information for determining processes that lead to understandings that make projections more valid and policy recommendations more pertinent and inevitably effective.

7.4.2 Southern California Coastal Region

7.4.2.1 Coastal Environmental Data Base

Coastal southern California is a region of extreme diversity. It ranges from beaches to forested mountains to deserts. The uses that man has put to the land are as varied as the landscape. Analysis of this complex environment requires accurate and easily usable information. The integrated study in which UCR is a participant necessitates the development of an environmental data base and a method of data display which will be adaptable not only to existing resource classifications but also to the needs and desires of potential users. The data will ultimately be put into a format compatible with computer handling, manipulation and mapping. The end result will be a geographic information system, upon which subsequent studies may be based (see Section 7.4.1.1).

The information is extracted from high altitude aerial photography from Mission 164 and from the U-2 flights associated with the ERTS-1 program. Mapping is performed from the transparencies to 1:24,000 scale USGS topographic sheets (Figure 7.7).

The first step was to map the characteristics of the physical environment, including hydrology, landforms and vegetation. Following this, general land use patterns are being mapped. (NOTE: the sequential nature of ERTS-1 is allowing us to update these general land use patterns.) Several specific phenomena are under investigation:

Figure 7.7. Orientation ERTS-1 photo for studies under Section 4.2; coverage includes Orange, South Los Angeles, West Riverside and North San Diego Counties.

land use changes, both within urban areas, and at their fringes; transportation networks, and recreation land use. The data afford the opportunity for assessing the impact of land uses upon the environment, seen in vegetation changes, change in quantity and quality of open space and "natural" areas and expansion of various types of recreational activities.

Two individual investigations have resulted, thus far, from the coastal studies: Mapping of Vegetation in the Orange County Coastal Region, and the Role of Recreation Sites and Environmental Homesite Quality in Modifying Land and Property Values. The first is a detailed localized extension of the data base concept. The second utilizes physiographic and vegetative information as well as land use data in conducting the study.

7.4.2.2 Vegetation Mapping in Orange County

The objectives of this study were twofold: (1) formulate a vegetation classification scheme useful for and functionally related to remote sensing techniques, and (2) map the vegetation habitats in Orange County, displaying the patterns on USGS topographic sheets.

Two data sources were used: Mission 164, CIR transparencies, 1:60,000 scale; and Mission 498, CIR imagery, 1:131,000 scale.

The imagery was evaluated initially to determine the kinds of vegetation habitats which are readily visible on film. Field checking was than used to determine the meaning of the photo signatures. The resulting classification contained nine categories:

1. Grassland (G)
2. Coastal Sage (S)

3. Chaparral (C)

4. Oak Woodland (O)

5. Pine Woodland (P)

6. Riparian Woodland (R)

7. Freshwater Marsh (F)

8. Salt Water Marsh (M)

9. Urban/Man Altered (U)

Figure 7.8 is a sample of the mapping which was done of Orange County.

7.4.2.3 <u>The Role of Recreation Sites and Environmental Homesite Quality in Modifying Land and Property Values</u>

The purpose of this paper has been to evaluate the major forces influencing the behavior of land and property values in two southern California coastal communities. Both cities, Oceanside and Santa Barbara, exhibit substantial recreational resources, and are noted for their pleasant residential environments. These two phenomena served as the focus of this study. It was felt that the specific nature of these two towns, being functionally simple, and located in an attractive setting, should exert an identifiable influence upon the structure of residential land and property values.

The traditional approach to expressing land value behavior is a model which shows the highest values near the Central Business District of a city, decreasing radially away from the CBD. This pattern resulted from the competitive bidding for land in a location most favorable for whatever land use was proposed. Transportation or accessibility represented the most important factor influencing

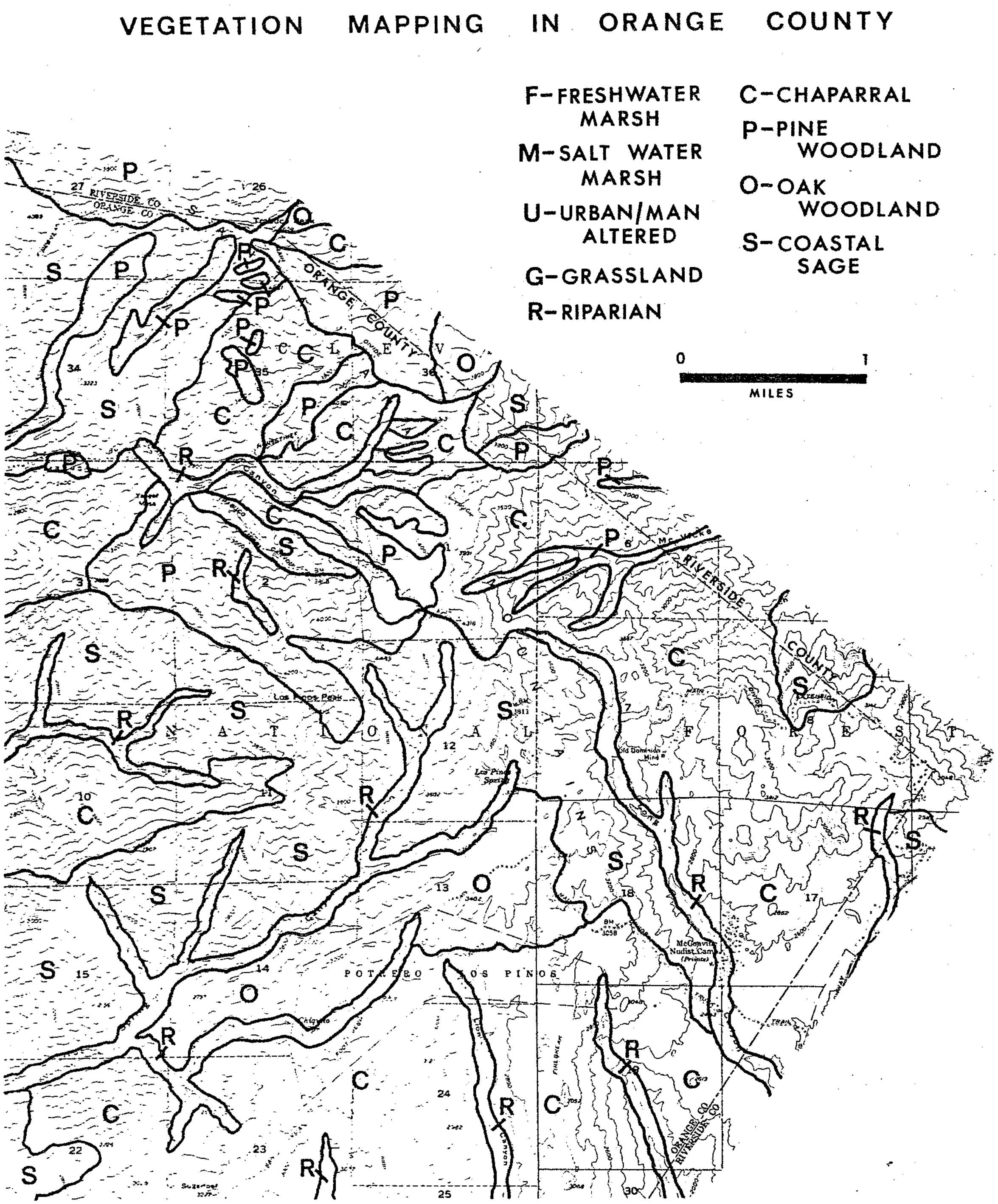


Figure 7.8. Representative portion of vegetation map prepared for Orange County, California, with the aid of Color Infrared "High Flight" aerial photography.

the value of land. Modifications of the theory, and subsequent empirical studies have revealed that land values tend to follow the concentric pattern, but with "islands" of high value in various locations. Land uses associated with these "islands" were generally industrial or commercial, but occasionally high-valued residential. The fact that emerged was that no strict relationship between land use types and land value had been formulated that accurately described real conditions.

The general theory was abstracted to state: land values are found to be highest in association with land uses whose functions and characteristics give these uses some economic and social importance. This importance, relative to others in the community can be measured as a force of attractiveness, or centrality. Centrality does not refer necessarily to a physical condition, but to the impact the land use has upon its locality, both economically and socially. It is this force of centrality which is the focus of high land values. The land use, in any specific location, associated with "central places" varies according to the function and location of the city. In a city like Santa Barbara or Oceanside, where the CBD is small and regional retail centers are important, other land uses may acquire greater importance as "central" functions. That recreation, as an economic and social force, is so important in these two cities suggests that location of recreational facilities might play an important role in the behavior and structure of local land and property values.

The assessment of the recreational function, and the quality of homesite environments was accomplished through the development of

indices designed to describe the nature of the functions in housing areas in each census tract. The index for recreation was based upon the type and quantity of facilities within each tract. Studies have shown that various socio-economic groups possessed somewhat characteristic preferences for certain types of recreational activities. As regards local residents, this fact suggested that certain kinds of recreational facilities should be associated with specific types of residential neighborhoods. Exclusive activities such as private golf courses, polo grounds, etc., should be found only in neighborhoods containing primarily high-valued houses in an environment with restricted traffic patterns. Conversely, recreational activities which cater to mass use tend to associate with neighborhoods with high living density and traffic patterns. There was also found to be a difference in residential structure between these neighborhoods.

Homesite desirability was assessed in terms of six surrogates: (1) slope gradient; (2) slope direction; (3) elevation; (4) local relief; (5) distance from the ocean; and, (6) natural hazards. Each tract was evaluated according to all six criteria and an index value assigned.

Regression analysis was performed using the recreation index and the topographic index as dependent variables, and using land value as the independent variable. The data were also displayed in tabular and map form. This permitted an interpretation of data with consideration of geographic characteristics as well.

The evaluation of the data revealed a strong correlation between the assigned recreational index and land values (.70). The highest

residential land values occurred in association with significant quantities of "quality" recreational facilities. The specific type was dependent upon the kind of neighborhood under consideration, verifying the assumption made earlier regarding facilities and neighborhoods. Tracts with low recreational index values were those with low land values, except in just a few cases, in which non-residential land uses were present.

Recreational tracts were described and characterized in two ways. Tracts can be evaluated in terms of economic structure. It is possible to determine the kinds of economic activities and their importance in the tract. The specific characteristics they exhibit, and their relationship to recreational activities provides additional information about the overall impact of recreation on a region. A second way, more appropriate to residences, is one which deals with vacation housing. An index of numerical importance and the rent quotients indicate the quantity and relative costs of vacation homes and apartments in a tract. It was discovered that tracts with high recreational index values contained large numbers of residences available for seasonal occupancy. The rent asked or median value of these vacation homes was in all cases, at least 15% higher than the median rent or price of homes in the tract. Assuming some homogeneity, this demonstrates both a demand for and a supply of such homes.

Given these data, it is fair to conclude that recreation has a sizable influence upon residential land values in communities in which recreation is a major economic and social function.

The topographic index value of each tract was plotted against its respective land value. The low (.22) correlation coefficient suggested

that the impact was low, if not coincidental. It was found, though, that total property value correlated much higher. More expensive, and larger homes are constructed in pleasant surroundings. This does not imply that low valued homes are not in a pleasant environment. Tracts bordering the ocean were assigned high topographic index values, but only rarely contained highly-valued homes.

Sites having low topographic index values, and, therefore, a lower homesite desirability, can be characterized as being located on flat alluvial surfaces with the view of the ocean blocked by hills. Land uses are mixed: residential, commercial and industrial. Property values tend to reflect the negative, as well as the positive impacts of site qualities.

Several tracts possessed attributes which were not explained by this analysis. They could be grouped into three classifications: (1) semi-rural agricultural, apparently with rapid ongoing conversion to urbanization, particularly residential land use; (2) industrial/commercial; and (3) educational. Each had high land values and few recreational facilities. The three conditions also tend to act in a manner to appreciate land values.

Land values are produced by a complex set of factors. Current theories assign the greatest influence to the central business functions of a city. In towns where CBD's are weak, where commercial and industrial activities are scattered, and where recreation is a major economic function, there exists a different set of factors modifying land value behavior. In communities like Oceanside and Santa Barbara, recreational facilities possess the social and economic force to act as "central" functions.

7.4.3 Environmental Impact Assessment And Environmental Monitoring

Stimulated perhaps by growing popular awareness of environmental conditions, one of a series of conservationist outbreaks occurred during the last four years of the 1960's and has continued on a somewhat diminished scale up to the present. Public interest has waned over the last three years, perhaps as a result of over-publicizing potential environmental problems, or perhaps as a result of competitive advertising by potential polluters. Two laws pertinent to this discussion are outcomes of this latest flurry of environmental concern. One is Federal legislation aimed primarily at government-sponsored projects or projects proposed for Federal lands (National Environmental Policy Act, 1969). The second is a California State law and is applicable to all development in California (Sections 21151 and 21152, California Public Resources Code).

This legislation, we can assume, represents an honest effort to cope with and solve the environmental problems of our society. Whether or not it accomplishes these ends will depend upon more than the quality of the legislation itself. The final determinant as to the success of the legislation will be controlled by a series of perceptual relationships, where attitudes and understanding of individuals involved in the processes of implementation dictate final outcomes.

Remote sensing technology provides a unique perspective from which we may view the manifestations of human impacts upon the environment. NASA regional scale imagery located at the Riverside campus provides data of such utility that it has been used for preparation of environmental impact statements (as required by California legislation) for site-specific projects within Riverside County (see Section 7.3

and Appendix II). High altitude imagery has also served as a data source for regional impact studies supported by NASA. Subjects of this research include assessment of the impact of off-road recreational vehicles throughout southern California, motorcycles in the Mojave Desert, the deterioration of desert habitats and archaeological resources resulting from urban and agricultural expansion in the Coachella Valley, and the actual and potential impact of one form of rapid mass wasting in the mountains of southern California.

Useful techniques for environmental monitoring are also under development. Work continues with a methodological expansion of mapping procedures for montane vegetation, and the use of the Joshua Tree (Yucca brevifolia) as a surrogate for soil moisture in the Mojave Desert. Techniques developed in this manner have high applications potential to resource management programs in southern California where large populations have significant impact upon environmental resources.

7.4.3.1 Habitat Deterioration in the Coachella Valley

Research objectives in the northern Coachella Valley involve the demonstration of high altitude imagery as a useful tool for monitoring urban-rural fringe land use change and associated environmental deterioration. The potential value of this test site is that the land use in settled areas is dominantly urban. The northern Coachella Valley has, as its economic base, tertiary services associated with recreational and resort activities. The area has (since the late 1960's) experienced continual economic growth, which is manifested in a spectacular transformation of open space to urban land uses.

Previous remotely sensed records of land use in the valley were acquired in 1967 and 1969. These will serve as a historical basis for

comparison and change identification. As of this writing, no decision has been made to utilize capabilities of our geographic information system. Both mapping and graphic display will be accomplished by non-automated methods.

Several preliminary maps have been attempted and completed. Ground truth procedures have indicated that the northern Coachella Valley is an especially compatible area for the use of high altitude data. By using the film as an ultimate source (adjusting the classification scheme to what is visible and not to what is presumed to be there), four different urban and three other categories (seven in all) were identified. The base period for this area is 1966, as detailed land use maps as of that date are available.

When compared, these maps (Figures 7.9 and 7.10) result in a map of land use change (Figure 7.11) which locates one areal focus of development. This focus, along the axial center of the valley, had previously been in open space. Concurrent investigations have determined that this increasing human activity is jeopardizing numerous natural habitats in addition to the sand dune areas along the valley center, as pointed out by the sequential land use maps. Other threatened areas include fan surfaces emanating from the San Jacinto Mountains, and the Bighorn sheep habitats in the high desert surrounding the valley bottom.

Continued residential construction has also reduced the habitat value of the valley to man. Increased environmental pollution (air pollution, noise and visual pollution) threaten the area's economic base. Results stemming from the lack of attention to specific

Northern Coachella Valley

1966 Land Use

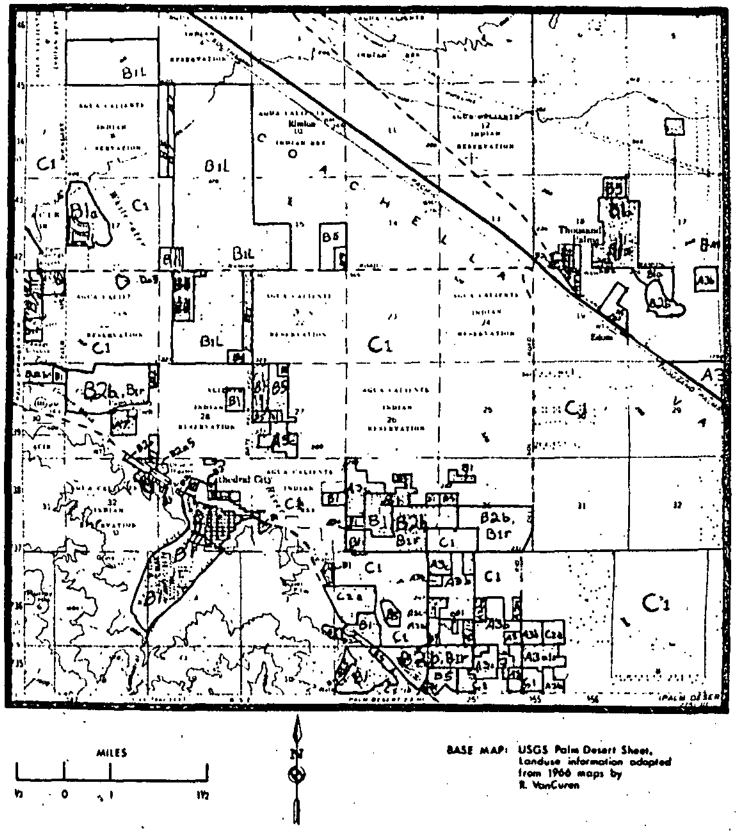


Figure 7.9. Land use map for Coachella Valley as of 1966.

1972 Land Use

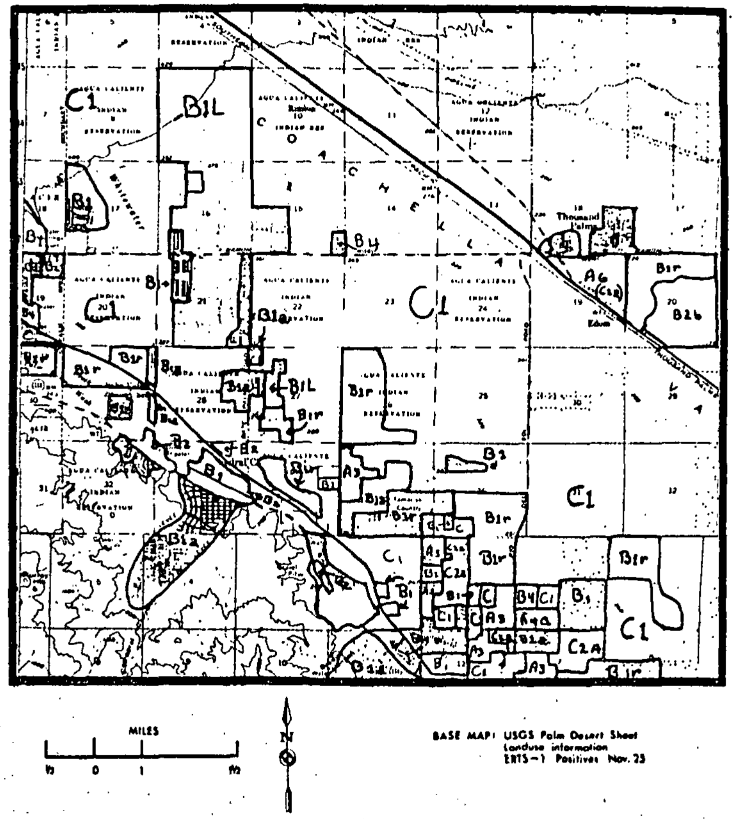
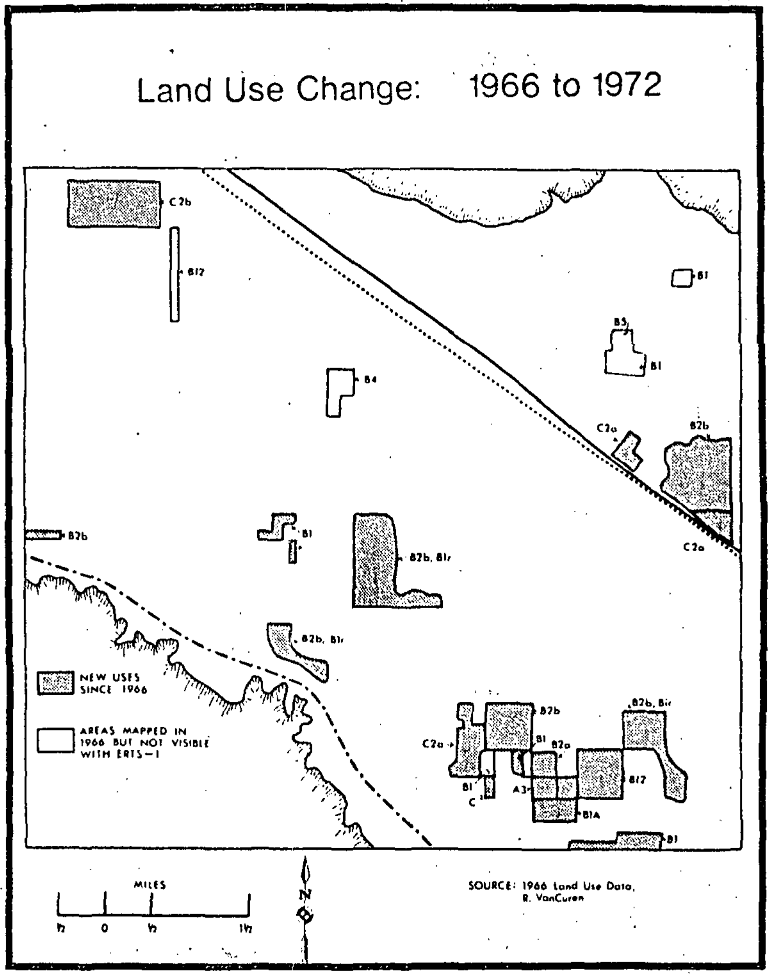


Figure 7.10. Land use map for Coachella Valley as of 1972.



COACHELLA VALLEY LAND USE CLASSIFICATION (1973)

A. AGRICULTURAL LAND USES
1. Field Crops
   a. grains
   b. feed
   c. vegetables
   d. truck crops
   e. other
   p. pasture
2. Row Crops
   a. vegetables
   b. maize
   c. other
3. Tree Crops
   a. citrus
      1) orange
      2) lemons
      3) grapefruit
      4) limes
      5) other
   b. vineyards
   c. palm orchards
      1) date
      2) ornamental
   d. other (i.e. pecans, etc.)
   a/c palms with citrus
5. Rural Housing and Agricultural Services
6. Unidentified or Unknown
7. Miscellaneous Agriculture
   a. nursery
   b. feed lot
   c. other agriculture (experiment station)
   P_p. packing plant

B. URBAN LAND USES
1. Residential
   a. single
   b. multiple
   c. transient
   m. mobile
   r. recreation
2. Commercial
   a. sales & service
   b. recreation
3. Industrial
4. Institutional and Government
5. Unknown

C. UNDEVELOPED AND UNUSED
1. Vacant
2. Abandoned
   a. agriculture
   b. urban

Figure 7.11. Changes in land use of Coachella Valley between 1966 and 1972.

recommendations concerning environmental design, and impacts of continuing development, are apparent through remote sensing techniques. Sequential imagery has recorded the Coachella Valley's continuing environmental deterioration.

7.4.3.2 Impact of Off-Road-Vehicle Operation on the Mojave Desert

Recreational use of off-road-vehicles has, especially in the arid areas of the western United States, become an important and rewarding leisure-time activity. Nevertheless, off-road vehicular traffic, especially motorcycle traffic, has already caused considerable damage to these delicate desert environments, and this damage will certainly become more widespread unless regulatory action is taken promptly to prevent overuse and destructive uses of the terrain.

Location of damaged areas and the study of their proliferation would aid greatly in efforts to minimize the impact of this vehicular traffic. Such study would also provide a basis upon which to establish regulatory policy for off-road-vehicles.

In the first study, the utility of remote sensing techniques for the dual purposes of location and study of damaged area is explored. Using imagery of California's northern San Gabriel bajada, spanning the nearly three years from July, 1968 to April, 1971, all major areas of off-road vehicular damage within the study region were located. Expansion of damage for the time period in question was also mapped for specific locations.

Small scale imagery (1:100,000 - 1:120,000) was found to be most desirable for purposes of initial location of damaged areas. Larger scale photography (1:24,000 - 1:30,000) was found to be more appropriate for more intensive study once damaged areas had been located.

CIR and stereoscopic film characteristics were also found to be valuable throughout the investigation. Imagery of damaged areas from more than one date is, of course, requisite for a temporal comparison for expansion of damage.

The second study evaluates change incurred during a motorcycle race which is held annually. Both high altitude (1:120,000) CIR imagery and low altitude coverage (variable scales), taken with hand-held 35 mm cameras and using color infrared film, was used to complement ground coverage taken both before and after the race at specific study sites. An attempt is being made to evaluate the resulting environmental changes. As part of an on-going study, the investigators are mapping those desert surfaces and textures which are most adaptable to intensive off-road-vehicle operation. For this, ERTS-1 imagery is proving to be most valuable.

Remote sensing techniques have direct application to the tasks of locating and studying off-road-vehicle damage. Aerial survey is clearly superior to ground survey for this purpose for several reasons. First, the use of aerial photographs renders vast areas examinable quickly. Second, the perspective offered by aerial photographs allows the interpreter to easily see spatial patterns not readily visible from the ground. Finally, the number of man hours required for a ground survey and mapping of damaged areas probably render that method prohibitively expensive. Aerial survey, therefore, has a clear cost advantage.

7.4.3.2.1 Remote Sensing of Off-Road-Vehicle Damage on the Northern Bajada of California's San Gabriel Mountains

The problem of off-road-vehicle (ORV) damage is especially great in arid environments. Slight disturbances can have profound repercussions

on the biota in these areas because vegetation regrowth is typically very slow. Many areas of the desert are covered with a thin cap of desert pavement which retards wind erosion. Once this cap is removed by intensive vehicular traffic or other means, wind erosion increases markedly. Moreover, many of the smaller shrubby plants found in deserts are dry and brittle most of the time. Thus, they are easily broken by passing vehicles, often resulting in their destruction. This problem is compounded after periods of intense rainfall; where native plant cover and desert pavement are disturbed, severe erosion is more likely.

Undoubtedly, the most destructive use to which ORV's are put is hill climbing--an activity which is largely restricted to motorcycles. Hill climbing requires a certain type of terrain; the slope must be steep enough to be challenging but not so steep or irregular as to preclude climbing. The most favored surfaces are those of hard packed clays or other reasonably cohesive materials. Because this type of terrain is not ubiquitous, where it does exist it tends to be intensively used.

An initial survey of the northern bajada of the San Gabriel Mountains utilized high altitude CIR imagery to identify areas which have been damaged by ORV activity.

The Baldy Mesa area proved to be more severely damaged than any other in the study area (Figure 7.12). Imagery dating from June, 1968 to April, 1971 was available for this site; therefore, it was selected for intensive analysis. The 1968 imagery was taken at a scale of 1:24,000 and the 1971 photography at a scale of 1:60,000 (Figure 7.13; note the 1968 imagery was enlarged).

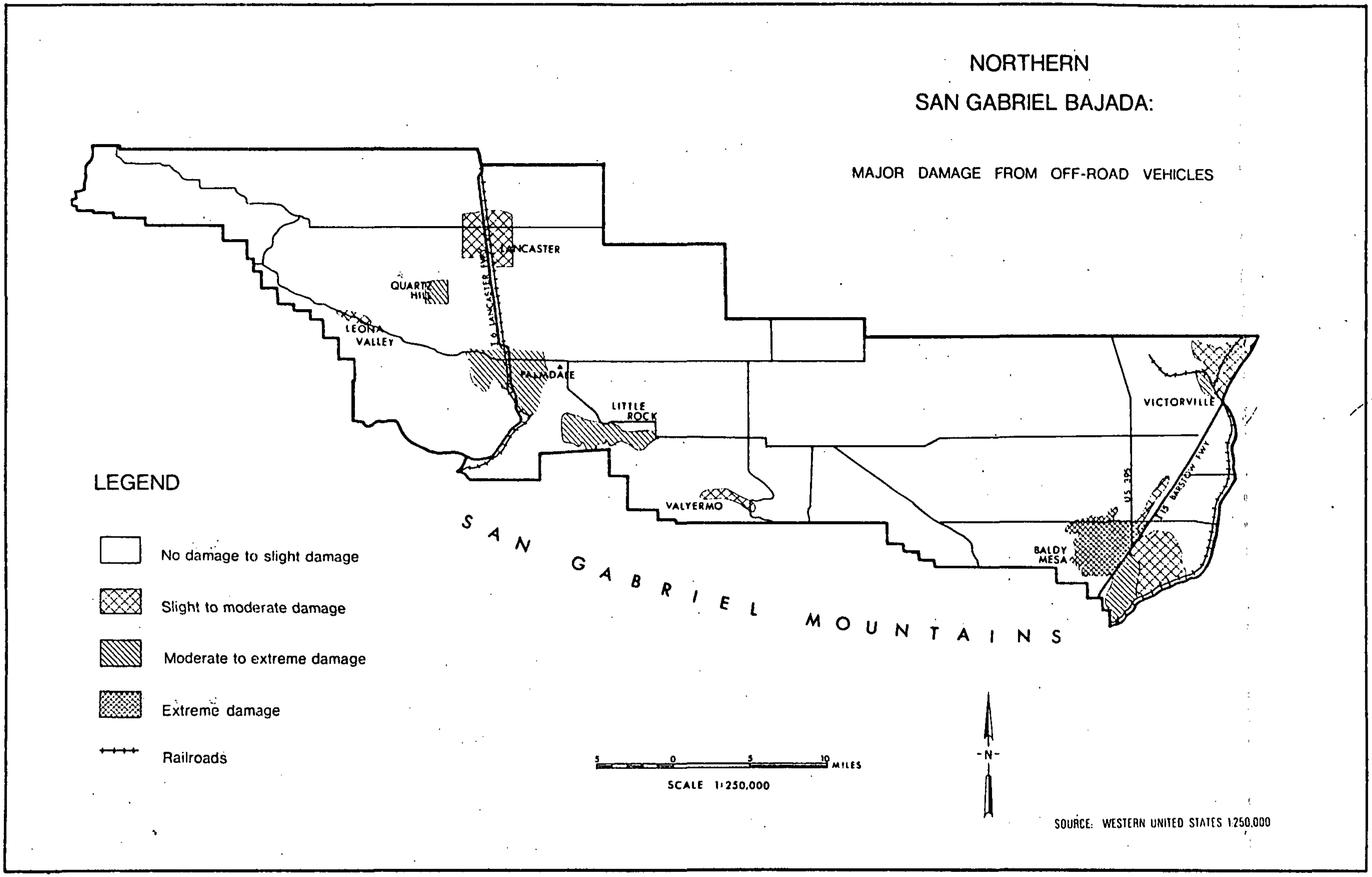
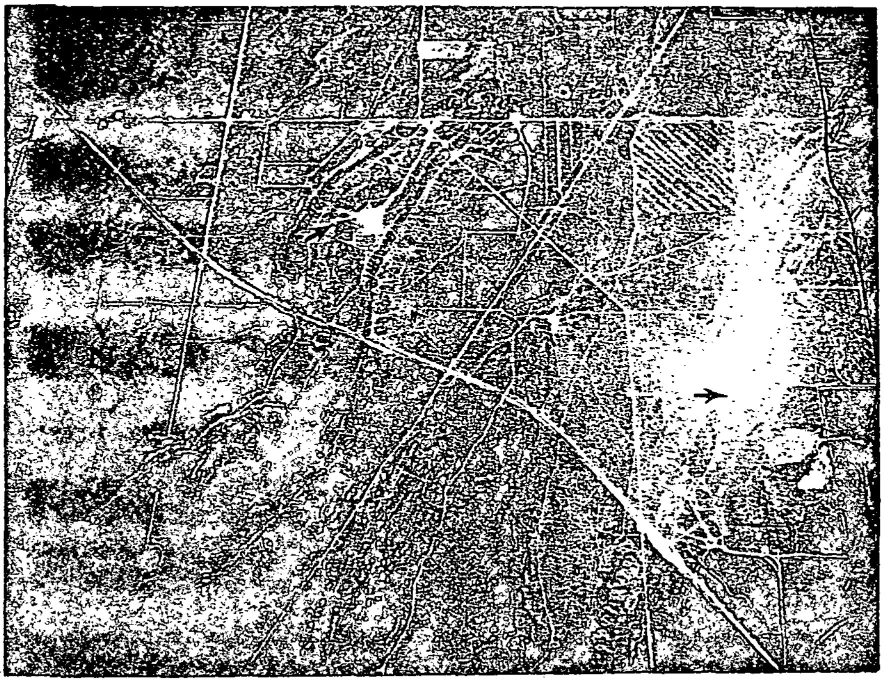
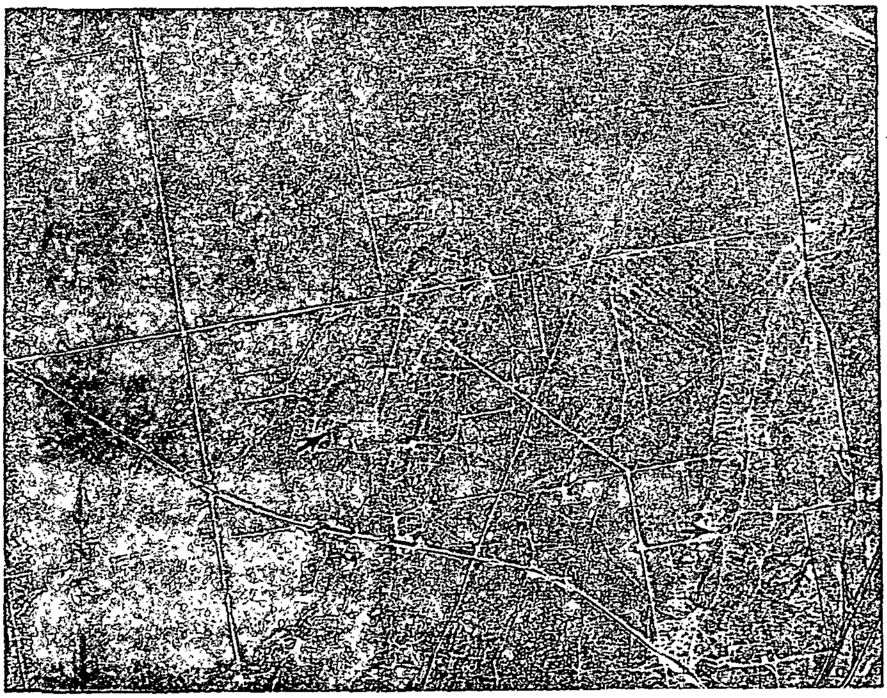


Figure 7.12. Map showing major damage caused by off-road-vehicles in the Northern San Gabriel Bajada.



1968



1971

Figure 7.13. Damage from use of off-road-vehicles. The arrows indicate typical examples of the effects which ORV usage may bring about over a two or three year period (1968-1971).

The Baldy Mesa study area was delimited and maps of vehicle damage were prepared using the aforementioned imagery (Figures 7.14 and 7.15). Five categories of damage, ranging from slight damage to barren ground, were used in compiling these maps. Subjective judgement was used in establishing boundaries and in determining which trails and roads would be represented.

A comparison of the resulting maps shows the deterioration which occurred in the short time span from June, 1968 to April, 1971. (More recent work is being done with imagery from December, 1972.) Expansion of damage in the area of Oro Grande Wash is most notable. The expansion of areas which are totally barren is also striking.

Several interesting patterns emerge on both of these maps. First, most severe damage is localized in the vicinities of the major washes which dissect Baldy Mesa. These washes, of course, offer excellent hill climbing terrain. Second, the partial barrier to traffic imposed by the Southern Pacific track and the almost total barrier provided by Phelan Road are noteworthy. The former is easily explained. The grade requirements of the railroad are such that its way is cut into the surface of Baldy Mesa and is elevated on earthworks where the track crosses each of the washes. As such, the points at which the track can be easily crossed by a vehicle are few. On the other hand, there seems to be no such ready explanation of the drastic reduction of damage on the north side of Phelan Road. Ground survey indicated that there are no effective fences on the north side of the road and the terrain is similar to that found on the south side. Nothing

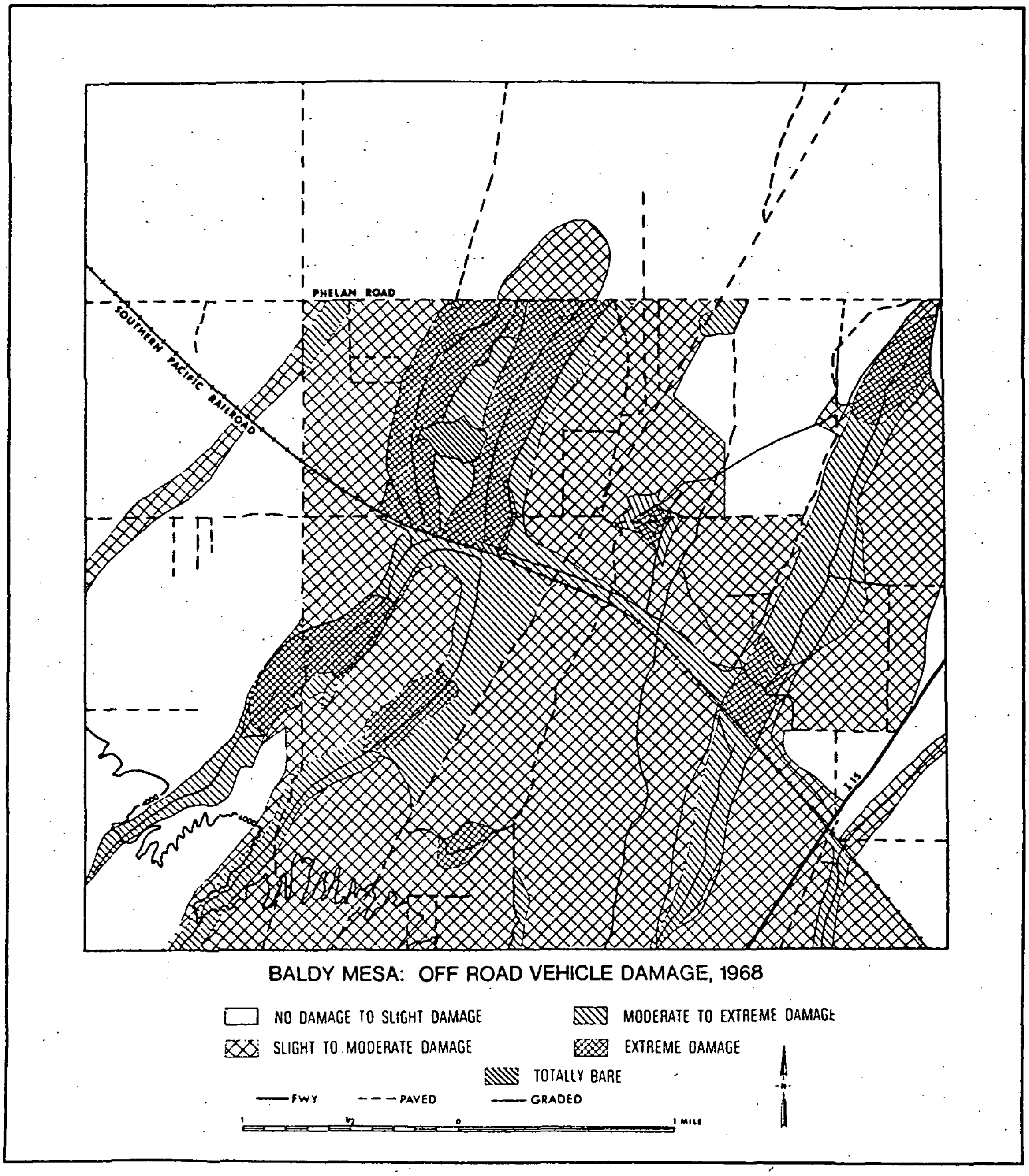


Figure 7.14. Map showing various degrees of damage caused by off-road vehicles in the Baldy Mesa Area as of 1968.

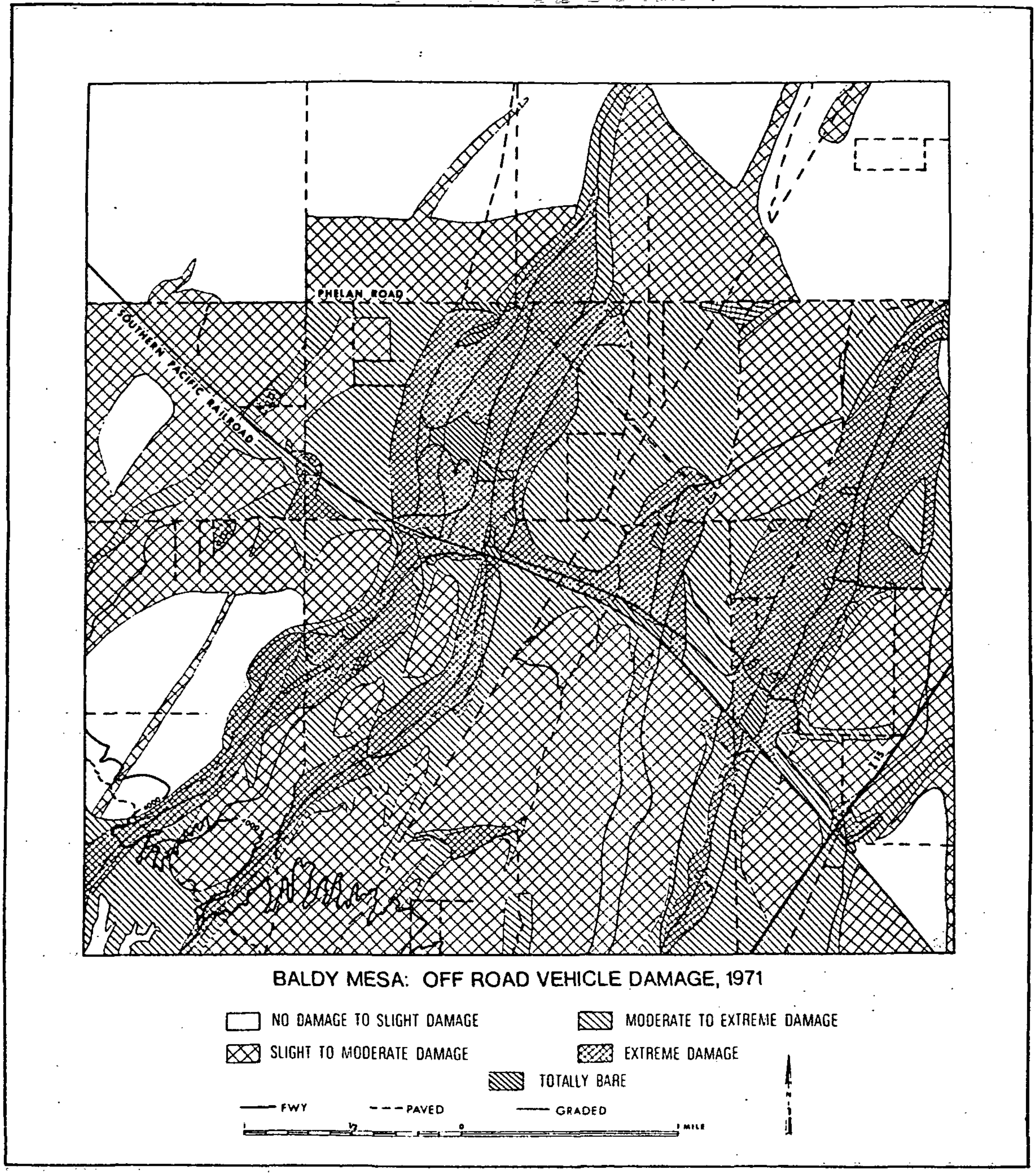


Figure 7.15. Map showing various degrees of damage caused by off-road vehicles in the Baldy Mesa Area as of 1971.

more concrete than habit seems to be causing this pronounced break in vehicular damage.

A ground survey of Baldy Mesa was made on Friday, October 13, 1972. It is interesting that the investigator did not encounter one other motorcyclist in the field, though he remained there all afternoon. This fact suggests that almost all of the damage which has occurred at Baldy Mesa has been the result of weekend activity.

Certain types of damage, especially littering, defacing, and vandalism, not evident from the aerial imagery, was noted throughout the study area during this ground survey. Because Baldy Mesa is not an established park of any sort, no trash receptacles are present and the problem of discarded garbage is great.

Nevertheless, it was apparent remote sensing analysis was a better method than ground survey for the study of these damaged areas. First, the air photo provides a permanent visual record of the study area which can easily be compared to subsequent imagery for change detection. Second, the patterns and extent of damage are not as easily discernible from the ground. For example, the influences of the Southern Pacific right-of-way is not easily visible from the ground but shows up clearly on aerial photographs. Finally, the detail available in a ground survey is not needed for analysis of all aspects of environmental damage caused by ORV's. Moreover, such excess detail would probably be detrimental to the study. For example, any attempt to map all of this information would result in under-generalization of detail, unworkably large scale, and needless confusion. For other, specific studies such as impact upon soil texture and individual plants, ground study seems more appropriate.

Remote sensing techniques have considerable value for the location and study of environmental damage caused by ORV's. These techniques also seem superior to and cheaper than ground study of this phenomenon. Stereoscopic CIR imagery at a scale of about 1:30,000 seems ideal for these purposes. Annual coverage of a study area, taken along the same flight line, would be extremely valuable in that it would facilitate temporal comparisons.

The general banning of all ORV's is a harsh measure and is probably not necessary for environmental protection nor is it socially desirable. However, controls and regulations are obviously needed. Because hill climbing is by far the most destructive use of ORV operation, this activity should certainly be restricted to specific, regulated locations. Baldy Mesa and other areas which have already been subjected to severe overuse are unlikely to regenerate. Thus, they might be made into such parks. Enforcement of these restrictive regulations would probably not be as great a problem as one might first assume because hill climbing areas have tended to be highly localized anyway. Remote sensing techniques would undoubtedly be valuable as aids to policy makers in establishing such regulations.

7.4.3.2.2 Impact of the Barstow to Las Vegas Motorcycle Race

This study utilizes high altitude color infrared imagery (U-2 platform) and low altitude coverage (handheld 35 mm cameras) for evaluating the effects of off-road-vehicle (ORV) operation in the Mojave Desert. The particular area examined was the route of the annual Barstow (Yermo) to Las Vegas Motorcycle Race, involving 2,500 riders, held in November of last year. Conclusions at this

point in time are supported by ground checks at specific sites which were selected for detailed study. Through image analysis and proper ground checks, an attempt is being made to determine what types of desert surfaces can best withstand intensive ORV usage.

The areas affected included the most common types of Mojave Desert terrain; alluvial fans, playas and washes. These features vary in their ability to accommodate intensive ORV recreational usage and the amounts and nature of damage that they incur.

Damage that was anticipated, again, varied with the type of material involved. First, the surface soil was expected to be altered. A slight cementing of stable desert surface materials is to be expected because of the net upward movement of water, that carries with it dissolved minerals which are deposited at the surface. Any weight applied to this surface would necessarily break it, exposing the looser subsurface material. In this process, the surface material is compacted. The result is a surface with high erosion hazard by both wind and water, underlain by a relatively impervious subsoil. The surface is therefore (allowed to be) denuded of its surface layer, the compacted subsurface promoting the lateral movement of water and preventing, in large part, the germination of plants that could promote erosion control.

This type of effect would be greatest upon alluvial fans. However, the degree of damage is largely dependent upon the portion of the fan that is used. This is necessarily a function of the depositional characteristics associated with stream velocity, slope and channel width. Coarse debris is better able to withstand intensive

usage, and is found at the head of the fan since it is the first deposited (a result of its greater weight). Materials increase in fineness and susceptibility to damage as slope decreases or distance from the source increases.

Desert pavement is subject to similar, though less intense damage, since it is a resistant surface but located on a relatively level area. Once the surface is broken, subsurface material is most susceptible to wind and water erosion.

Playas require a slightly different consideration. Soil textures are fine, but the area serves as the local base level, effectively eliminating water erosion hazards. The slightly structured playa surface is therefore only susceptible to wind erosion. Perimeters of playas, however, are some of the most likely archaeological sites in a desert environment, and may be subject to destruction.

Washes, in regard to usage, are blessed with instability. Sudden convectional showers that typify desert storms, and their resultant heavy runoffs, greatly rework these ephemeral stream channels at frequent intervals. No desert surfaces can form and the coarseness of the sands in their beds resist compaction. Vegetation that inhabits stream courses is also adapted to frequent change.

Much of the damage that is inflicted on these areas results from the reaction of the riders to the particular surfaces over which they ride. Flat, or expansive, vegetation free, firm surfaces are most attractive, because they allow greater speed. The qualitites that are attractive to the rider are those which make it most susceptible to damage. These are, by and large, fans, playas, and pavement surfaces. Washes, those areas that can withstand heavy usage,

are the slower, concentrated parts of the course. Because of its looseness, riders slow down and tend to follow single-file.

Initial examination and comparison of both before and after U-2 CIR imagery has proven less useful than hoped. The main reasons for this are: (1) the expected change did not develop to the degree anticipated; (2) rider attrition during the race was greater than expected; and (3) by following a specific and relatively narrow predetermined route, the riders upset a minimum of terrain. Figure 7.16 shows the width of the route from both low altitude and the ground at two separate locations near the halfway point. Indications are that organized events such as this race, following a specific route, tend to do less damage overall than random ORV operation, which is a much more common and widespread occurrence. Analysis of all imagery and ground study allows the following tentative conclusions to be made. Damage at this point does not appear to be particularly serious or extensive. In consideration of the number of people who derived pleasure from this event, suspension of the event does not seem warranted. Most important, in those areas which experienced damage, there were alternate routes that would have resulted in minimal change. In addition, surface texture is not only important to ORV operation but is being found to be a more rigorous controlling factor in the determination of vegetation type than was previously suspected.

Present investigation involves use of both U-2 and ERTS-1 imagery for the mapping of desert surfaces which can best withstand ORV operation. Initially, those areas that are most easily detected are

Figure 7.16. Upper photograph, taken from low altitude aircraft near the halfway point, shows the relatively narrow path of disturbance formed by the motorcycles. Lower photograph, also near the halfway point, shows path width at ground level; note the dust cloud developed over Soda Lake area (rear of picture).

delimited, those being areas of rock outcrops and playas as well as major stream courses. These areas also represent the two extremes in elevation and gradient, the rock outcrops forming the steepest slopes, the playas being level. There is also, generally, a continuum of material texture from very coarse to very fine proceeding from the rock outcrops to the playas, so that relative textural determination can be inferred from slope position.

This work has been done thus far on the I^2S Color Combiner from an image without any enhancement. Texture as determined from relative slope position on this imagery has proven to be difficult due to differences in parent material. It appears that the mapping of surface texture may be more successful in these intermediate areas from density-slice enhanced image, and work will continue in this direction. These results will lead to improved recreational planning of all types in areas where an environment may be easily damaged.

7.4.3.3 Mapping Montane Vegetation - A Methodological Revision

A previous NASA-funded study developed a method of using CIR imagery to identify and map montane vegetation in southern California (Minnich, Bowden, Pease, 1969). An addendum to the original study which was produced in the 1971 annual report has been expanded this year under NASA support into a more detailed and sophisticated methodology for vegetative mapping using remotely sensed imagery. The entire system is too lengthy to reproduce as part of this report. However, the following synopsis with examples should illustrate the utility and potential accuracy of this methodology. The region for which the methodology was developed is limited to southern California,

but the application potential of this technique extends to any brush or tree-covered area for which there is high-altitude imagery.

In the study of the San Bernardino Mountains the most effective use of CIR was found to be as a basic data source. Whereas previously, either due to limited coverage of aerial imagery or due to underlying theoretical constraints, CIR was only an accessory to montane vegetation mapping, this study utilized the film as others use a field survey. The field survey yields information upon which the vegetation analyst bases his classification. In this mapping methodology, only data which could be extracted from the imagery was considered significant to the development of the classification.

Recently, a 7.5' quadrangle was mapped in greater detail than previously. This mapping has extended and revised Mr. Minnich's classification. Figure 7.17 illustrates the formulation of the classification and the important parameters by which each class may be identified. Texture, physiognomy, seasonal variation, and traditional photo-interpretive clues have been cited, as well as the false color signature of CIR. It is these characteristics, in concert, found throughout the study area, which yield consistent data for the classification.

The "Family Tree" concept (Figure 7.17) demonstrates how the classification grows from single species identification or multiple species identification. For example, the unit of coastal sage has a distinctive signature. The species within the unit are not separable. The distribution of the unit is of sufficient size at the scale of mapping to warrant a class. Similarly, the species <u>Ceanothus crassifolius</u>, <u>Rhus laurina</u> and <u>R. ovata</u> may be identified in association but not as

separate species. These species are found in the study area only with Adenostoma fasciculatum. The combination is mapped as C_S. Adenostoma fasciculatum is found in association with the three species mentioned above but its signature is unique in this environment. Where Adenostoma fasciculatum is found without associates, it can be mapped as Caf.

Communities by Munz (1965)	Species Identified		Associations
COASTAL SAGE	Artemesia Californica ---) Encelia farinosa --------)	CS	--- COASTAL SAGE
	Adenostoma fasciculatum	-- Caf --)	CHAMISE CHAPARRAL
	Ceanothus crassifolius) Rhus laurina) Rhus ovata)	---------)	C_S--SOFT CHAPARRAL

Figure 7.17. "Family Tree" (Vegetation Classification Illustration)

As overlapping distributions become more complex, the "tree" becomes multi-branched, but the principle remains the same. Single species may combine to form separate and distinct classes with unique distributional characteristics.

Accuracy in vegetation identification from areal transparencies is fundamentally dependent on whether the photographic scale allows plants to be recognized individualy or en masse. If plants cannot be individually resolved, or are more easily identified by population, "impurities" will undoubtedly appear in the classification system and in areas demarcated. In the latter circumstance, inaccuracy can be reduced by sample inspection of individuals. Where plants are too small to be resolved, the most outstanding omissions result from inconspicuous species which are rarely abundant but may be widespread in distribution. For example, field observations showed the shrubs

Prunus ilicifolia, Rhamnus crocea, and the yucca Yucca whipplei to be widespread but unmappable species of the chaparral association.

Other difficulties stem from distributional variations within each association. Species which occur in concert are referred to as multiples. Each species within a multiple may appear in any proportion and some may be entirely absent. On the other hand, color and textural signatures of a multiple are a result of distinctive leaf reflectance properties and morphological features of the species in concert. Additionally, the likely possibility that monoecious stands formed from any one of the constituent species would be identified separately from imagery implies that a multiple reflects a thorough species mixture. Horton's observations of Upland Conifer Forest, for example, indicate that constituent species of the coniferous tree multiple (Pinus ponderosa, P. jeffreyi, Abies concolor, and Libocedrus decurrens) are widely distributed throughout the area he mapped (Horton, 1965).

The theoretical need for transects depends on the accuracy requirements of the map. At the broadest level, each association should have representative transects throughout its range (though beyond the scope of this investigation) to convince the reader that certain species actually exist together. A transect across the film is also real, since the map is based on imagery patterns. Not only can one designate overlap of species ranges, but also can identify plants either to the single or multiple level. Even unmappable isolates that are "impurities" to the prevailing association may be separated.

7.4.3.4 Yucca brevifolia: Distributional Factors and Use for Detection of Near-Surface Moisture Retention

It was our intention to isolate the major controls which govern the distribution of the Joshua tree (Yucca brevifolia). For the purpose of this preliminary investigation, we focused upon areas of Y. brevifolia which were within two hours driving time of Riverside, California, and chose for detailed study only those sites which appeared to have the most dense and healthy stands of Yucca. Thus, the sites studied probably possess optimal physical conditions for the plant's survival. The following discussion centers on climatic and edaphic parameters, parameters felt to be of primary importance, at least within the study area.

CLIMATIC PARAMETERS

Temperature

The California desert is generally described as hot and dry, but on a transect through the desert one notices distinct vegetation changes; changes resulting from climatic variations and associated edaphic conditions. Accordingly, climatic parameters were considered basic to this investigation. Initially, temperatures were analyzed in order to determine a possible relationship between climatic temperateness and the distribution of Y. brevifolia. This analysis was abandoned due to paucity of data needed at specific locations. Temperature factors do come into play in two respects, however. First, the Yucca seed germinates in warm to hot temperatures, and second, the Yucca appears to require the relatively cold winters characteristic of the high (Mojave) desert. These factors allow for a general delimiting of the Yucca's domain, in California, as portions of the high desert. Considerations of temperature then gave way to moisture analysis.

Moisture

The high desert, although always deficient of moisture by definition, does receive a significant percentage of its meager precipitation during the high sun season. Both the Gulf of Mexico and the Gulf of California represent source regions for maritime tropical (mT) air masses which influence the desert during the summer season. Maritime tropical air possesses two distinguishing characteristics: warm temperature and moderate to high moisture content.

Circulation patterns and the usual thermal low pressure system developed over the desert in summer initiates influx of this mT air. Once over the strongly heated land surface, convective processes are triggered. In contrast to the low (Colorado) desert, the high desert complements this convection with orographic influences. Resulting summer precipitation in the Mojave, intense but scattered convective storms, coupled with the desert's sparse winter cyclonic precipitation, leads to a degree of bimodality in the precipitation regime of high desert stations. These stations receive a greater percentage of their total precipitation during the high sun season than stations located within the low desert. The following figures serve to illustrate this characteristic:

Selected Stations (elevation)	Percent of Total Precipitation Falling April-September	Average Annual Precipitation
High Desert		
(1960-1971) Joshua Tree (2,730 ft.)	40 percent	4.8 inches
(1961-1971 incomplete) Mountain Pass (4,739 ft.)	47 percent	6.4 inches
(1961-1971) Twentynine Palms (1,975 ft.)	60 percent	3.6 inches

(continued on next page)

Selected Stations (elevation)	Percent of Total Precipitation Falling April-September	Average Annual Precipitation
Low Desert		
(1961-1971) Palm Springs (411 ft.)	18 percent	4.6 inches
(1961-1966) Borrego Springs (625 ft.)	24 percent	3.1 inches

Not all stations located in the high desert show this large a percentage of summer precipitation. Some stations are located in areas which receive moisture by surface and subsurface flow (e.g., at the base of the San Gabriel or San Bernardino Mountains).

The primary factor governing the distribution of Y. brevifolia in the area studied is the availability of water during the high sun season (the season of seed germination). To be sure, not all areas in the high desert which receive summer precipitation have Joshua trees. Thus, attention must then focus on edaphic conditions.

EDAPHIC PARAMETERS

In an effort to isolate any edaphic factors which might control the distribution of Y. brevifolia (Joshua Tree), soil samples were taken during the course of a series of transects across Yucca core areas and adjacent sites not vegetated by Yucca. Preliminary comparisons of the Yucca-bearing soils and the non-Yucca bearing soils (Figure 7.18) were then made, while keeping all other (non-edaphic) variables as nearly constant as possible, although future investigations are planned, in order to verify further the following tentative conclusions.

Soil pH ranged from 6.8 to 9.0, with both the median and the mode occurring at about 7.8. However, pH values did not vary in any

systematic way with Yucca _v._ non-Yucca site locations. Thus, within the broad ranges of pH tolerance of the Yucca, which includes at least the span 6.8 to 8.2, soil pH does not seem to be a critical factor governing Yucca distribution.

Similarly available soil nutrients also seem not to be significant relative to Yucca distribution. It was thought initially that available base nutrients might account for the somewhat random occurrences of Yucca, especially with respect to the present regional juxtaposition of surfaces exhibiting "soils" of Recent and (more humid) Tertiary pedogenic regimes. Although consideration of time and expense precluded precise, quantative evaluation of available soil nutrients, microscopic examination of soil minerals revealed all soils in this area to be the product of the decomposition of granitic bedrock and, except in the case of alluvial horizons with wadis or on fans, to be _in situ_. The Tertiary "grussoil" was identifiable on the basis of being more arkosic than the less-extensively weathered Recent granitic debris. However, the distribution of Yucca core areas did not coincide with the distribution of Paleo and Recent soil surfaces.

Textural analysis of the soils, however, proved to be very useful and enables the determination of the edaphic factors regarding Yucca growth. Figure 7.18 summarizes soil texture at the sites analyzed in this study.

Non-Yucca soils are reasonably-well sorted, while the Yucca-supporting soils are bimodal, with maxima in the medium-coarse sand and silty clay fractions (.75Ø and > 4Ø8Ø). This textural composition, obviously, is highly moisture-retentive and understandable as

S I T E S U M M A R Y

SAMPLE	SITE LOCATION	VEGETATION	SOIL TEXTURE
1	Old Woman Springs: wash slope above playa	Creosote; no Yucca	Well-sorted: F. sand max.
2	Waller Road: less than 3000'	Creosote; desert sage	Well-sorted: Med. sand
3	Landers: top of bank of first oued	Yucca	Bimodal: C. sand, clayey silt maxima
4	Landers: bottom of first oued	No Yucca	Well-sorted: Med. sand
5	Interfluve between two wadi	Much Yucca	Bimodal: C. sand, clay silt maxima
6	Pipes Road: bottom of second oued	Much Yucca	Well-sorted: Med. sand
7	Pipes Canyon: 6250'	Much Yucca	Well-sorted: C. sand
8	Pipes Canyon: 5000'	No Yucca	Well-sorted: C. sand
9	Pipes Canyon: 4650'	Yucca	Well-sorted: C. sand
10	Pipes Wash: at windmill, _c_. 3510'	Yucca	Well-sorted: C. sand
11	Pipes Wash: below windmill, _c_. 3500'	No Yucca	Well-sorted: C. sand
12	Joshua Tree National Monument: under 3000'	No Yucca	Well-sorted: C. sand
13	Joshua Tree National Monument: under 3000'	No Yucca	Well-sorted: Med. sand
14	Joshua Tree National Monument	Cholla	Bimodal: C. sand, silt
15	Joshua Tree National Monument	Dense Yucca	Bimodal: C. sand, silt
16	Joshua Tree National Monument: alluvial fan above Twenty-Nine Palms	No Yucca; Creosote	Well-sorted: C. sand
17	Joshua Tree: same fan	Dense Yucca	Bimodal: C. sand, silt
18	Joshua Tree National Monument: basin above fan	Dense Yucca	Bimodal: C. sand, silt
19	Same basin: clay playa	No Yucca	Well-sorted: clay
20	Yucca Valley	Much Yucca	Well-sorted: C. sand
21	Morongo Valley	No Yucca	Bimodal: C. sand, clay
22	Highway 138: past Wrightwood turnoff	Yucca; Juniper	Bimodal: C. sand, C. silt
23	Highway 138	Sparse Yucca; Creosote	Well-sorted: F. sand
24	Highway 138	Creosote	Bimodal: C. sand, v.f. sand
25	Highway between Palmdale & Lancaster	Yucca	Well-sorted: Med. sand
26	Same area	No Yucca	Well-sorted: Med. sand
27	Depression at Site 25	No Yucca	Well-sorted: V.f. sand, silty clay

<u>N.B.</u> "Yucca" refers only to <u>Yucca brevifolia</u>

Figure 7.18. Comparison of site parameters on Yucca-bearing vs. non-Yucca-bearing soils.

Yucca-supporting (as opposed to the well-sorted soils) if the upper Mojave Desert is accepted as a climatically tense environment in which *Y. brevifolia* is able to survive only where there is available sufficient soil moisture. Soil moisture thus becomes the limiting factor governing Yucca distribution which, in turn, is controlled by soil texture, given a certain minimum of precipitation. Within certain extremes, soil texture is only important where optimal soil moisture is required for Yucca survival.

Precise soil moisture determinations were performed with the aid of a soil resistivity meter which, although unable to discriminate between the very dry Yucca core areas and non-Yucca areas, did reveal a large amount of available soil moisture in the bottom of Pipe's Wash. Even though soil texture is not ideal for Yucca, subsurface flow in the wash from the San Bernardino Mountains permits Yucca growth.

The significance of optimal soil conditions for moisture retention is additionally confirmed by the fact that *Y. brevifolia* tends not to occur on pedimented surfaces, on which the depth to bedrock very rarely exceeds one meter. There simply is insufficient groundwater to support Yucca. The Yucca distribution patterns along the interfluves in Pipe's Wash further delimits this relationship, for Yucca avoids the dense *in situ* grus ridges sitting on granitic bedrock, while proliferating in the alluviated interridge basins.

CONCLUSION

The distribution of *Yucca brevifolia* clearly is a relict one. Yucca occurs only where soil moisture conditions are optimal. Air

masses are the overriding parameter governing this distribution. In most areas precipitation is just sufficient to enable Yucca to survive. Thus, Y. brevifolia occurs in soils with a bimodal textural composition, which facilitates maximum soil moisture retention. The corresponding physiographic environments are identifiable on both U-2 and ERTS-1 imagery. Present research involves the potential for mapping general textural composition of desert surfaces from the above-mentioned imagery.

7.4.3.5 Planning Archaeological Field Research in Coachella Valley, California With the Aid of Remote Sensing

Sixty-five years ago two aerial photographs taken by Lieutenant P. H. Sharpe of the British Army while on a routine mission in a war balloon found their way into the journal Archaeologia (Capper, 1907). These photographs depicted the megalithic ruins of Stonehenge on Salisbury Plain. Since that time, archaeology and archaeological methodology have been viewed through a different set of lenses, and the important field of aerial archaeology has contributed significantly to its parent discipline (Deuel, 1970). The contributions of aerial archaeology have been in two primary areas. The first of these has been in permitting aerial views of ruins or other ground phenomena such as the strange markings in the Nazca Valley of Peru (Kosok, 1947; Kosok and Reiche, 1949) and in the California desert (Setzler, 1952) or the ridged fields of Colombia and other South American countries (Denevan, 1970). Second, aerial photography has aided in the detection and recording of suspected but unknown archaeological remains (Gummerman and Lyons, 1971). This brief paper discusses a third, more fundamental application of aerial photography to

archaeology, that of planning archaeological field research, and using environmental surrogates to locate potential archaeological sites.

Recent advances in archaeometry (Michael and Ralph, 1971) have made it relatively easy to date many archaeological assemblages and thereby establish culture chronologies, and American archaeologists have directed their efforts more and more toward solving problems of cultural dynamics (Martin, 1971). It is to be expected therefore that certain research problems can be pursued in some regions but not in others. Since archaeological resources are non-renewable, tactical problems arise when critically important regions are being irrevocably altered by the spread of intensive agriculture, urbanization, or other forms of development which destroy the contextual association of archaeological remains. In such cases fieldwork can be more economically conducted, with respect to both time and money, if the undisturbed portions of the landscape can be identified prior to going into the field.

An example of planning archaeological fieldwork with the aid of aerial photography is the Coachella Valley archaeological project of the Archaeological Research Unit, Department of Anthropology, University of California, Riverside. The project is designed to investigate the adaptive alternatives employed by late prehistoric populations to conditions of environmental deterioration. The project is regionally specific in that it demands a setting which underwent environmental deterioration in the absence of significant climatic change. This specification is necessary because the impact of climatic changes on prehistoric human populations through varying the abundance

and distribution of critical food resources is at present difficult if not impossible to assess. Coachella Valley, California provides such a setting in that its lower end was innundated during the Christian era by fresh-water Lake LeConte (Blake Sea, Lake Cahuilla) for a probable minimum of 1,000 years (Hubbs, Bien, and Suess, 1965). The lake was fed by the Colorado River, and finally began to decrease in size when the river re-routed itself and flowed directly into the Gulf of California some four or five hundred years ago. The prehistoric lake-dwellers, who had previously existed on the relatively stable and abundant lacustrine resources including fish, shellfish, waterfowl, and aquatic plants, were then forced either to adapt to new environmental conditions and a complete reliance on non-lacustrine food resources or migrate from the area, possibly to coastal southern California (Aschmann, 1959). It was conceived that certain of the adaptive alternatives employed by the lake-dwelling population would be apparent in the archaeological residues of campsites along the lakeshore and on recessional shorelines which date to the final desiccation of the lake. The problem was then one of isolating intact portions of these shorelines.

While extremely arid, the Coachella Valley today, like the Imperial Valley to the south, is a region of intensive year-round agriculture. Irrigation water is largely derived from the Colorado River and enters Coachella Valley through the Coachella Branch of the All-American Canal system. In Coachella Valley, much of the shoreline of Lake LeConte and the archaeological sites along it were destroyed during construction of the Coachella Canal. Since the water

is largely distributed throughout the valley by gravity flow, it has been necessary to bench-level much of the valley floor below the elevation of the main canal. Thus, a brief review of modern agricultural practices in Coachella Valley (Nordland, 1968) made it apparent even without a photographic survey that a significant portion of the valley floor including much of the Lake LeConte main shoreline and recessional shorelines, along with the associated archaeological materials, had already been obliterated by "progress". In order to isolate the undisturbed portions of the valley floor which might yield the types of data required by the research design, and thereby most efficiently plan an archaeological survey, it was necessary to consult recent aerial photographic coverage.

A series of NASA color infrared transparencies, scale 1:131,000, 1:120,000 and 1:60,000 served as the data base. An example of this photography is illustrated in Figure 7.19. These photographs proved quite satisfactory for isolating the desired undisturbed areas of the valley floor. On the valley floor proper, it was in most cases possible to ascertain from the general appearance and maturity of the "natural" vegetation whether areas in question were actually undisturbed, or whether they had once been under cultivation and since withdrawn from production. Areas meeting the requirements of the research design were located on United States Geological Survey 7.5' and 15' topographic maps, which were then used in the field during intensive survey. Several hours of time spent in the laboratory examining the photographs was more than sufficient to locate

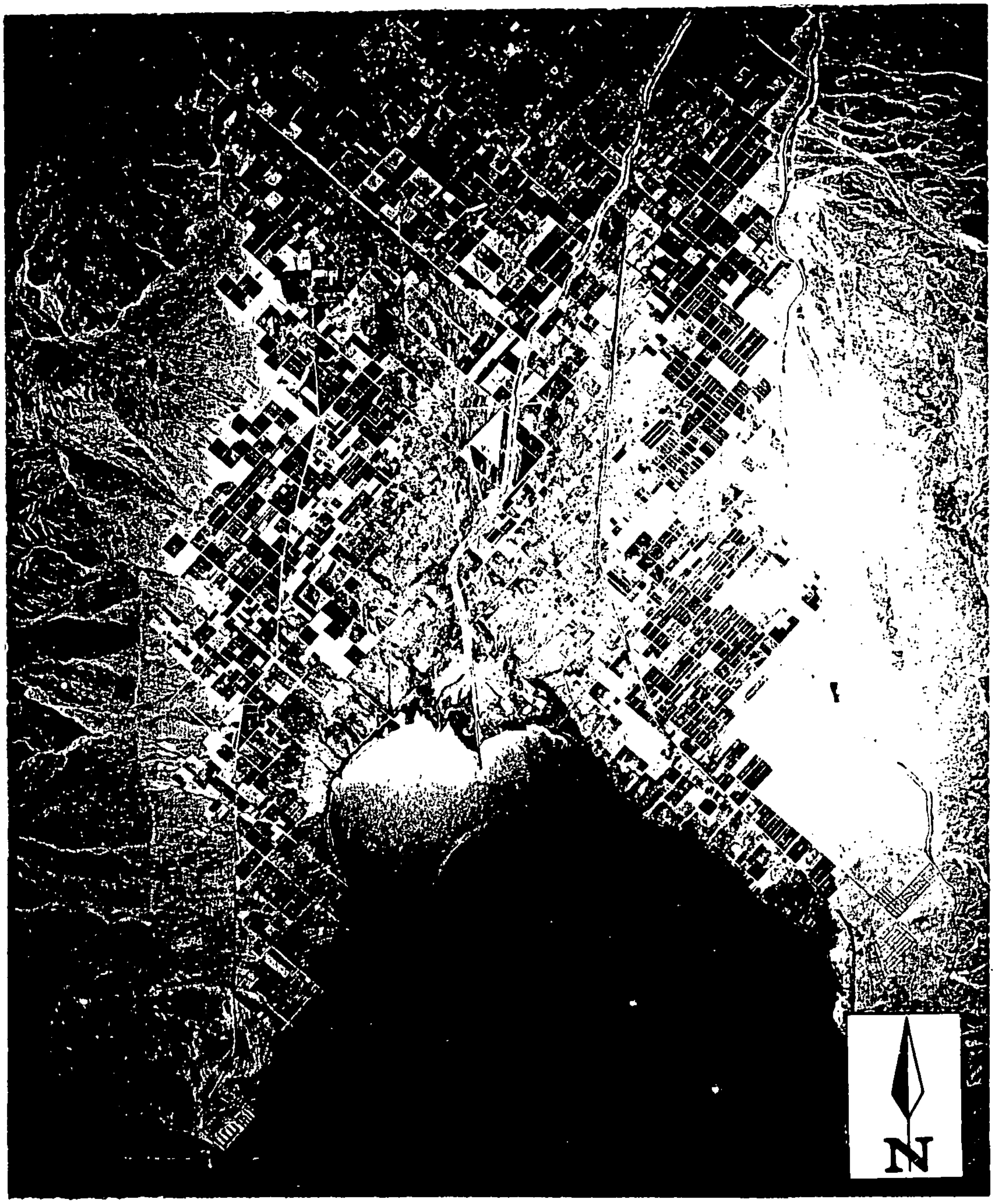


Figure 7.19. 1972 U-2 photograph of a portion of the Coachella Valley (cf. Figure 7.20.).

all potential survey areas in the valley, a task which would have required several weeks at great expense in the field. Figure 7.20 is a map which was developed to aid the field archaeologist.

Since the coverage depicted the landscape as it currently appeared, it permitted a more accurate assessment of the potential for archaeological research than the only other fairly recent coverage which was available (United States Department of Agriculture photographs flown in 1965). In only one instance had an area selected for intensive survey been developed before field work was started.

While a larger than regional scale would have been desirable for the actual location of such archaeological features as rock alignments, foot trails, fish traps, house rings, etc., which were ultimately located during the intensive field surveys, the smaller scale proved more than adequate for delimiting those areas with archaeological potential. Generally speaking, the smaller scale was probably best since the image could be enlarged 8x and viewed stereoscopically with the available laboratory facilities, while permitting a broader view which allowed easy orientation and thus saved time.

This aspect of aerial archaeology, the actual planning of archaeological survey, and the use of environmental surrogates such as landforms or vegetation to indicate the location of potential sites is of greatest utility to archaeologists whose objectives require them to work in regions that are either substantially

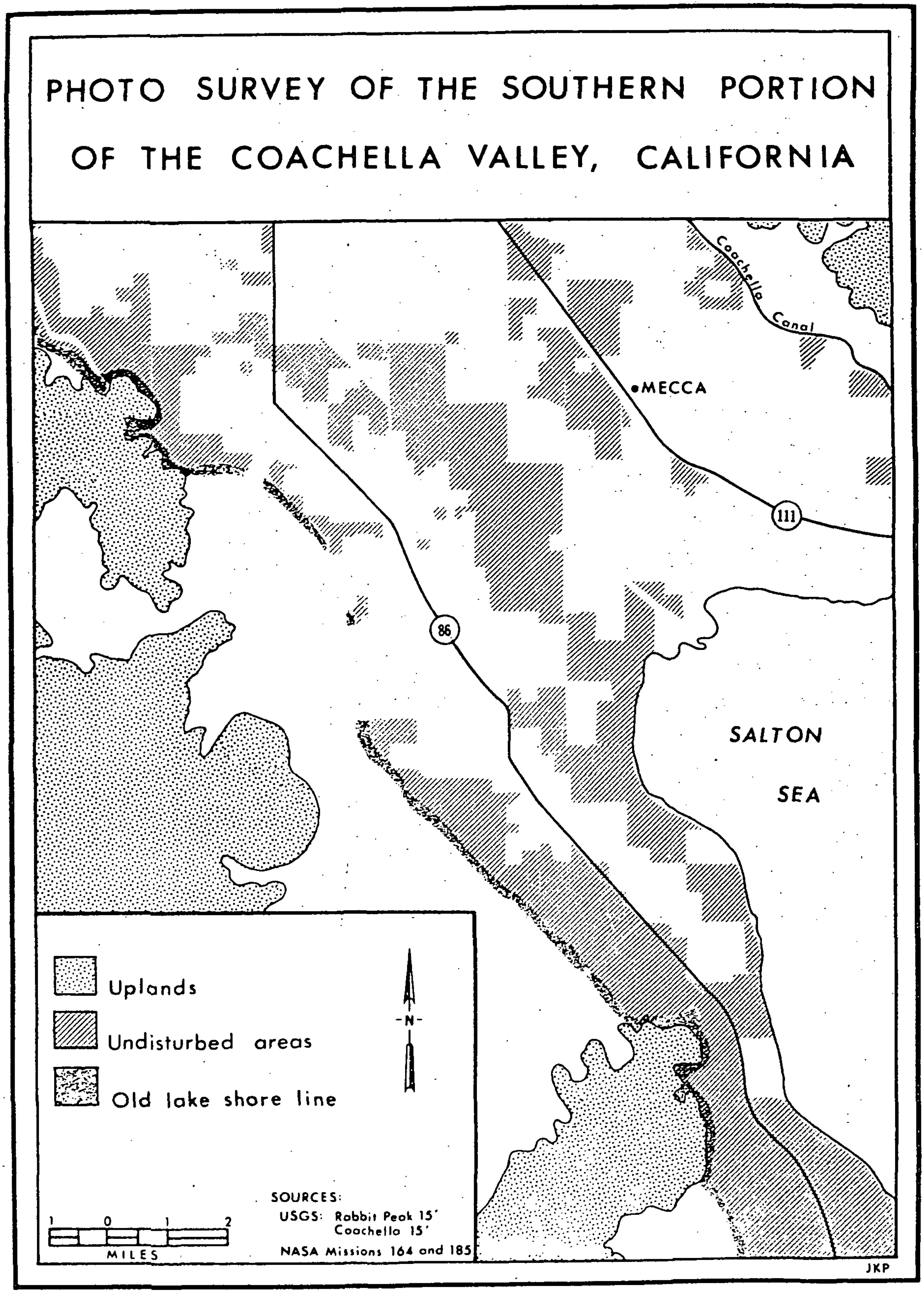


Figure 7.20. (Caption on facing page.)

Figure 7.20. (See facing page) This figure shows a portion of the floor of Coachella Valley laid bare by the recession of Lake LeConte 400-500 years ago. Archaeological sites occurring on undisturbed portions of the exposed lakebed and lacking evidence of wave action are therefore datable to the recessional and post-recessional period, and should yield the most direct evidence of the adaptation from lacustrine to xeric conditions. The east shoreline of the lake has been obliterated here by construction of the Coachella Canal. Lower portions of the lakebed were innundated by the Salton Sea rise of 1905-1907. Most of the lakebed shown here has been seriously disturbed by agricultural potential for the present research design, as indicated by hachure (undisturbed areas).

developed or that are in the process of being quickly developed. Archaeological surveys of such regions can best be conducted, maximizing data recovery, yet keeping field expenses to a minimum, if planning with aerial photographs becomes an integral part of the methodology.

References

Aschmann, Homer (1959), "The Evolution of a Wild Landscape and Its Persistence in Southern California," Annals of the Association of American Geographers, 49(3): 34-56, part 2.

Capper, Col. J. E. (1907), "Photographs of Stonehenge as Seen from a War Balloon," Science, 169: 647-654.

Denevan, William M. (1970), "Aboriginal Drained-Field Cultivation in the Americas," Science, 169: 647-654.

Deuel, Leo (1970), Flights into Yesterday, New York: St. Martin's Press.

Gummerman, George H. and Thomas R. Lyons (1971), "Archeological Methodology and Remote Sensing," Science, 172: 126-132.

Hubbs, Carl L., George S. Bien, and Hans E. Suess (1965), "La Jolla Natural Radiocarbon Measurements IV," Radiocarbon, 7: 66-117.

Kosok, Paul (1947), "The Mysterious Markings of Nazca," Natural History, LVI(5): 200-207, 237-238.

Kosok, Paul and Maria Reiche (1949), "Ancient Drawings on the Desert of Peru," Archaeology, 2(4): 206-215.

Martin, Paul S. (1971), "The Revolution in Archaeology," American Antiquity, 36(1): 1-8.

Michael, Henry N. and Elizabeth K. Ralph, editors (1971), Dating Techniques for the Archaeologist, Cambridge: Massachusetts Institute of Technology Press.

Nordland, Ole J. (1968), Coachella Valley's Golden Years, Coachella: Coachella Valley County Water District.

Setzler, Frank M. (1952), "Seeking the Secrets of the Giants," National Geographic Magazine, CII(2): 390-404.

7.4.3.6 The Deformation Characteristics of Hill Slopes and Channelways in Two Different Environments as Depicted by Remote Sensor Returns

Mass movement of slope materials in response to concentrated rainfall runoff occurs in all environments where high intensity rains are characteristic of the climatic regime. The type of mass movement varies from locality to locality, but generally the dominant forms are those of slide and flow which proceed rapidly downslope once initial movement begins. In this investigation only two rapid forms of mass wastage phenomena are considered: (1) mudflow, and (2) debris avalanche.

This study resulted from investigations into the effects of heavy rainfall and associated runoff on slope and channelways in two widely separated geographical areas: (1) the Appalacian Mountains in central Virginia, and (2) the San Bernardino Mountains in southern California. Climatically, the two areas are characterized by markedly different precipitation regimes although rainfall intensities attain similar magnitudes in both environments. Abnormally high precipitation yields associated with unusually intense cyclonic storms do occur, although infrequently. The high intensity rainfall and subsequent heavy runoff associated with these severe storms often result in extensive damage to hill slopes and channelways within the drainage basin affected by the storm. The damage is especially noticeable in the headwaters of these drainage basins.

A remote sensing approach to assessing the extent of flood damage to hill slopes and channelways in the two study areas mentioned above was undertaken for the purpose of describing the details of

the areas affected and for mapping the distribution of damage done. This approach eliminated the expenditure of large amounts of money and time in the field gathering data. Field inspection, however, was carried out in both areas for the purpose of spot-checking and substantiating information extracted from the aerial photographs.

The basic premise of this study is that aerial photographs can supply detailed information about hill slope and channel deformation resulting from heavy precipitation runoff associated with high intensity storms. Through an examination of analytical air photo procedures and their application to a study of mass wastage phenomena, the following objectives were identified: (1) to describe the character of the dominant mass wastage form found in two different geographical areas; (2) to develop criteria for recognizing and identifying the dominant mass wastage forms in an area; and (3) to compare the effects of storm damage in the two areas of study.

Upper Wildwood Canyon

Wildwood Canyon is located in San Bernardino County, California; the entrance to the Upper Wildwood Canyon watershed being 7.5 miles north of the city of Beaumont, California (Figure 7.21). The Upper Wildwood Canyon watershed is shown on the San Gorgornio Mountain, California topographic quadrangle (S.W.R.), 1:62,500 scale. The watershed is void of population: hence there was no damage to structures or loss of life.

The watershed encompasses an area of one square mile (approximately). Rocks which underlie the basin are igneous and meta-igneous

LOCATION OF STUDY AREAS

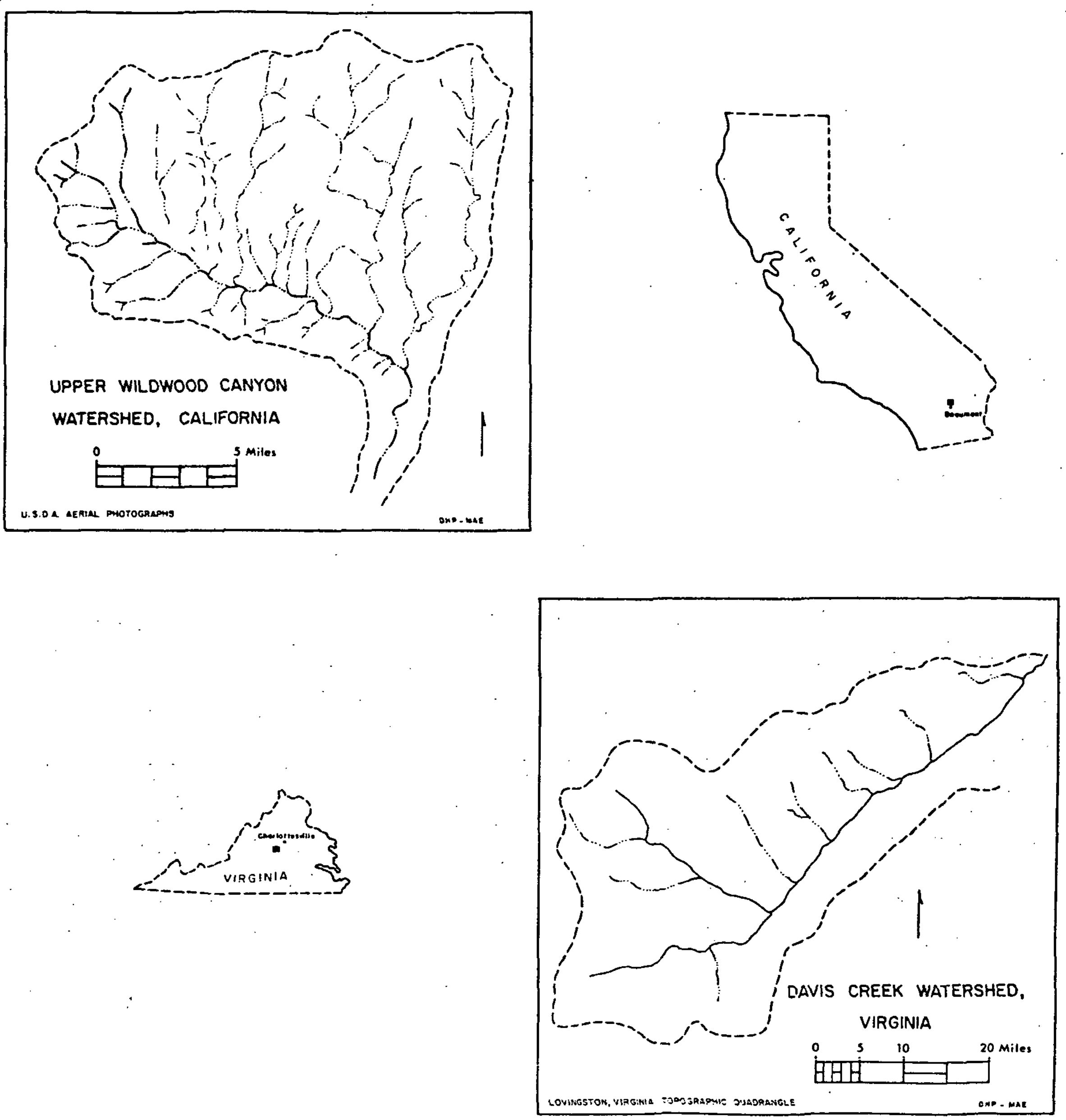


Figure 7.21. Location of areas used in study of the deformation of hill slopes and channelways.

and support slopes which are moderately steep to steep. Soils within the watershed are generally thin with alluvium and colluvium attaining considerable depth near the channelways. Vegetation cover within the watershed is moderate to sparse, consisting of grasses, chapparal, and scattered stands of oak.

Heavy rain persisted over the Upper Wildwood Canyon region during January and February, 1969. Alluvial and colluvial fill in the main channel of Upper Wildwood Canyon watershed collapsed as a result of heavy rains which occurred over the watershed on February 25, 1969. Steep slopes, scattered vegetation cover, and thin soils characteristic of the watershed facilitated the runoff of water associated with the storm. Rapid accumulation of runoff waters in the main channelway apparently permeated these channel deposits and after the saturation point was reached, the valley fill collapsed (Figure 7.22).

The type of mass movement which occurred in the upper watershed of Wildwood Canyon can be described as a mudflow. This type of mass movement is common in semi-arid regions where there is: (1) abundant but intermittent water supply; (2) absence of any substantial vegetation cover; (3) unconsolidated material containing enough silt or clay to aid in lubrication of the mass; and (4) moderately steep slopes (Sharpe, 1960).

The long axis of the Upper Wildwood Canyon drainage basin is oriented northwest by southwest. Topographically, the basin is asymmetrical, with the trunk stream oriented parallel to the basin's long axis and located near the west and southwest drainage divide.

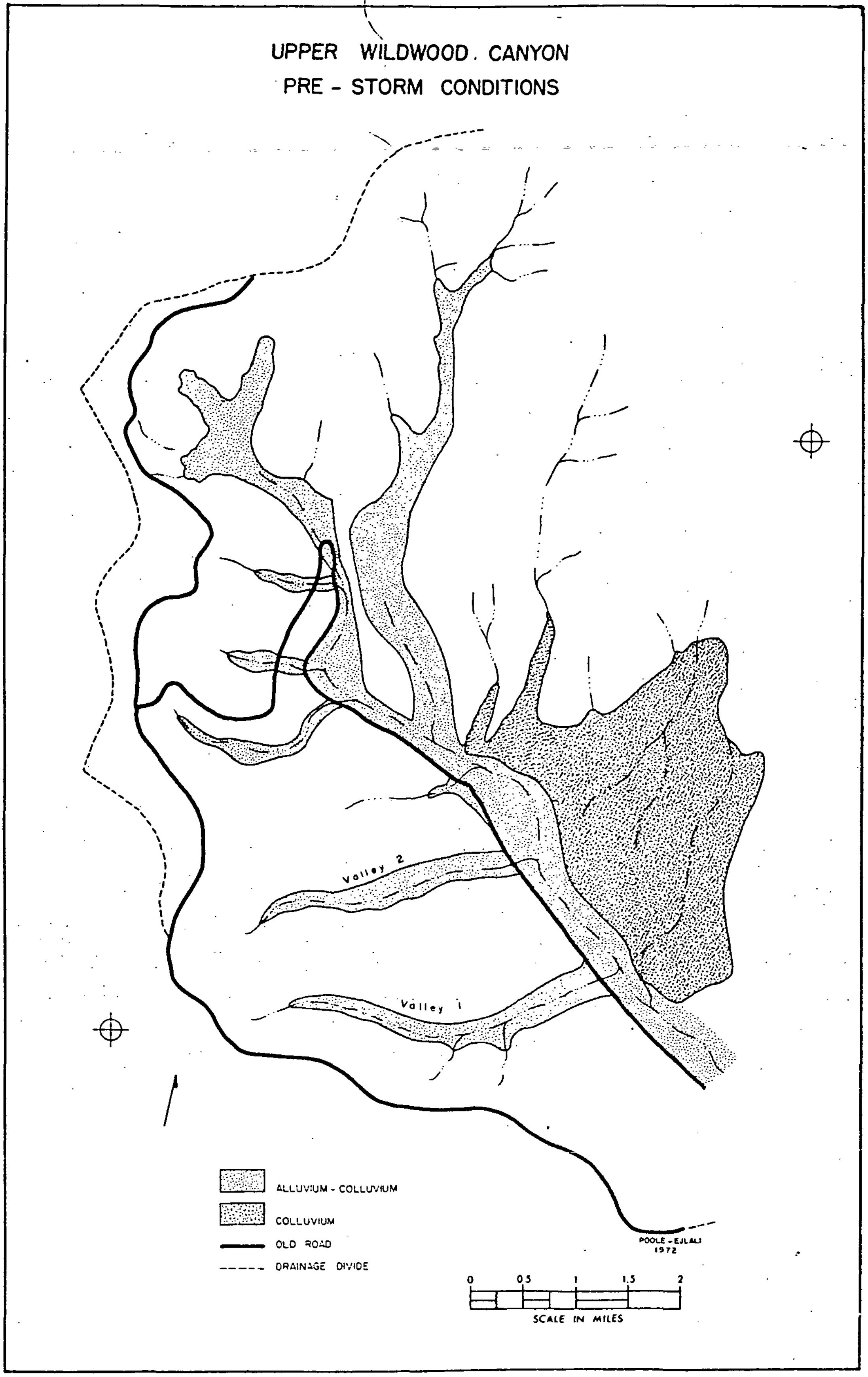


Figure 7.22. Map showing pre-storm conditions in Upper Wildwood Canyon.

Drainage lines west and south of the main channel are short compared to those draining the northern and eastern part of the basin. Many of these longer, south-flowing channels show considerable entrenchment along their lower courses. Consequently, their channels are lacking in extensive accumulations of alluvial and/or colluvial materials.

These longer channels with their reduced gradients, by and large, are discordant to the main channel at their junctions. This, generally, is not true of the shorter and more steeply graded streams draining slopes west and south of the main channel. In the latter instance, the considerable deepening of the main channel during the mass movement of runoff water through the system was responsible for the collapse of part or all of several of these tributary channels. In this manner, accordancy was established at their junctions with the main channel.

One exception of significance, however, needs to be mentioned. The channel fill in Valley 1 collapsed during the storm of February 2, 1969, while the channel fill in Valley 2 did not. In their pre-storm state both tributary channels display accordancy to the main channel. Both are of similar lengths and have similar cross-sectional asymmetries and contain similar amounts of alluvium and colluvium. Their respective vegetation patterns are similar. These similarities occur both on their channel floors and on their adjacent side slopes, although Valley 2 contains more large trees on its steeper side slope than is true of Valley 1.

There are dissimilarities between the two valleys which this investigator believes to be contributors to the fact that Valley 1 collapsed and Valley 2 did not. While their overall lengths are similar, their basin shapes and their adjusted individual tributary drainage nets differ. Valley 1 has two distinct lateral tributary channels draining the south slope, both of which partially collapsed during the storm of January 25, 1969, while Valley 2 has no distinct lateral tributary channels draining its side slopes.

Of equal significance to established lateral tributary channels as a contributing factor to the sediment collapse of Valley 1, is the geometric form of this valley. While both valleys are asymmetrical, with steep south slopes, the valley heads are markedly different. Form lines which show the general slope configuration within the valleys are arranged so that surface runoff is more highly concentrated at the head of Valley 1 and at the heads of the two lateral tributaries than in Valley 2. This concentration of surface flow around the valley and tributary heads in Valley 1 represents a greater concentration of erosional energy in these areas, which might explain, in part, why the valley fill collapsed. This is not to imply, however, that the points of initial failure occurred at the valley and tributary heads, since it is probable that such failures are transmitted both up slope as well as down slope. Rapid removal of the valley fill in the main channel could have initiated the collapse of the tributary fill. The heavier stand of vegetation on the south slope of Valley 2, the absence of sizable lateral

tributaries and the lower concentration of erosional energy around the valley head might be considered as contributing factors in explaining why Valley 2 did not collapse.

A sketch map based on information extracted from the aerial photographs depicting the Upper Wildwood Canyon mudflow above the collapsed tributary channel (Valley 1) is shown in Figure 7.23. The concentrated overland flow of water during the peak of storm runoff is noted by the numerous minor depressions lateral to the main channel. These depressions reflect in the concave (channelward) scars formed in the channel bank throughout the entire length of the main channel (south prong) on the southwest, and along the channel banks of the northern prong where channel entrenchment is maximum.

Figure 7.24 shows that not all of the channel fill (alluvium-colluvium) was removed by the mudflow generated by the storm. Only a single tributary (Valley 1) collapsed throughout its entire length. Partial collapse of channel fill occurred in only three tributaries south of the main channel and upstream from Valley 2. Much of the roadway (pre-storm) which followed the south bank of the main channel was destroyed by the mudflow. A new road constructed after the storm follows the north bank of the main channel. Remnants of the old road are clearly visible on the post-storm imagery.

Criteria which were developed in this investigation for the purpose of recognizing and identifying mudflows are as follows:

1. The flow is linear in plan but sinuous to the extent that channel configuration controls its general form,

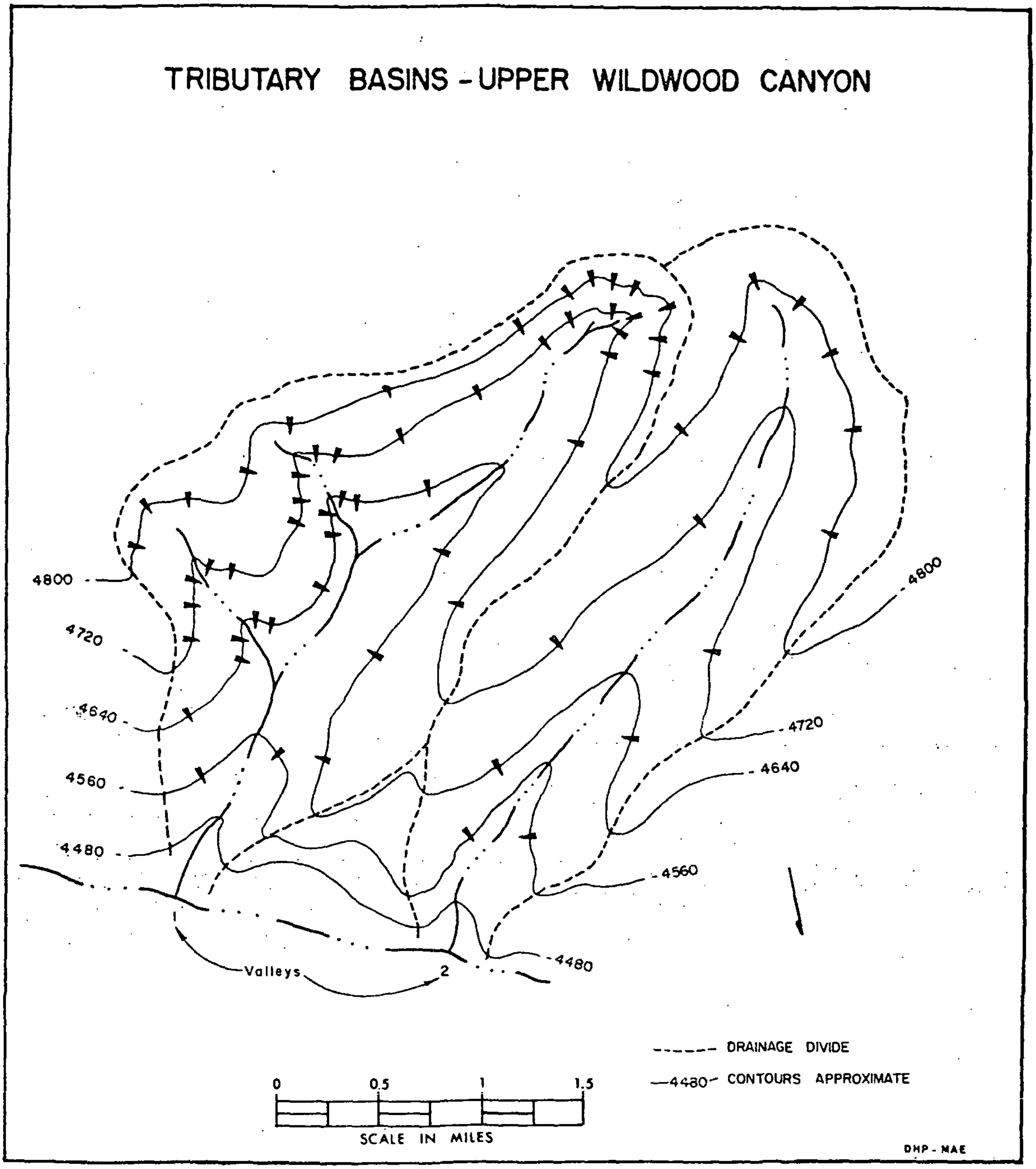


Figure 7.23. Map showing tributary basins of Upper Wildwood Canyon.

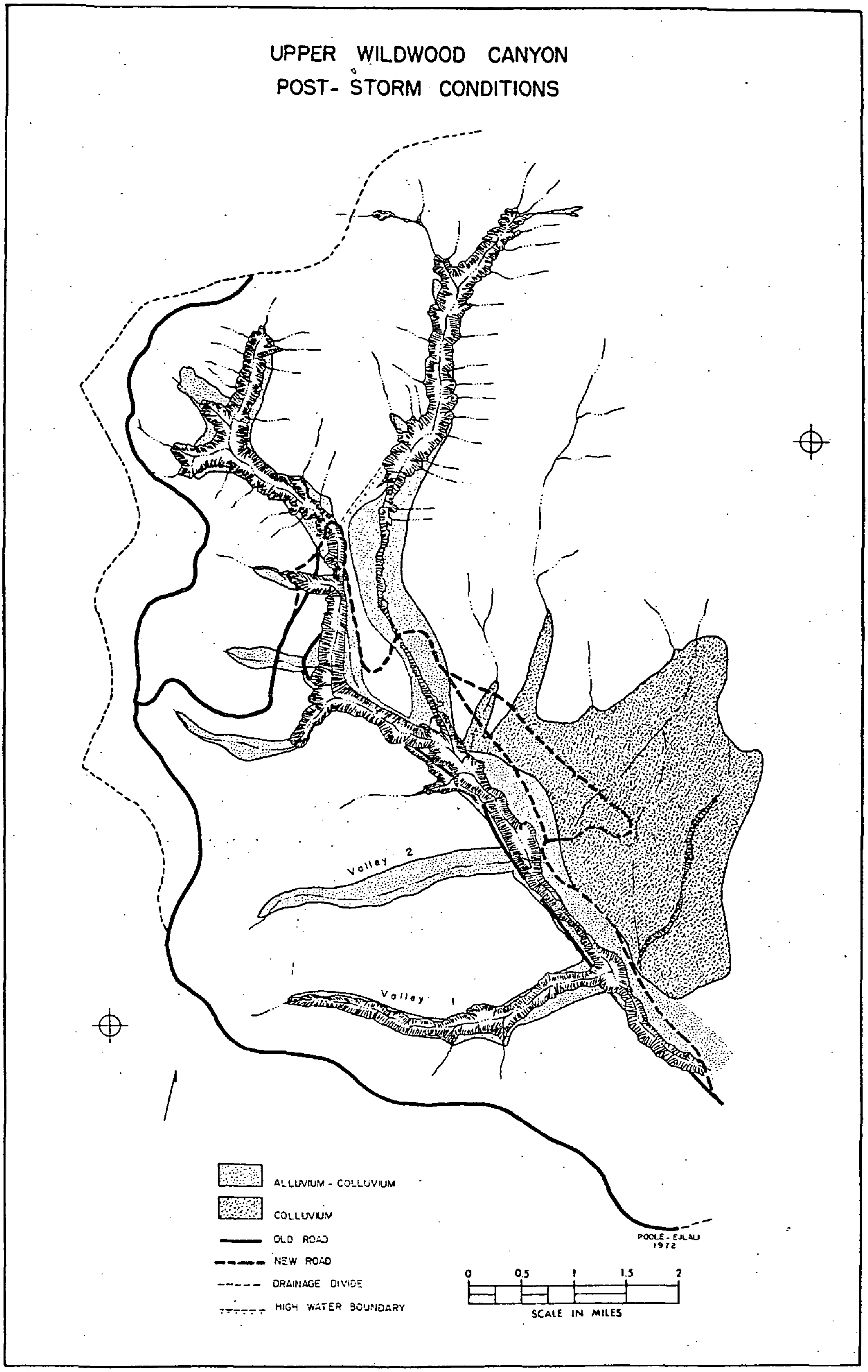


Figure 7.24. Map showing post-storm conditions in Upper Wildwood Canyon.

2. Where the movement of materials is controlled by channel configuration, one or more channel bifurcations are noted,

3. Tributary channels which contributed their channel fill to the mudflow are accordant with the main channel at their junctions,

4. Unaffected tributary channels display discordancy at their junctions with the main channel,

5. On both Ektachrome infrared and on black-and-white photographs, the trace of the mudflow appears light in contrast to darker colors reflected by surfaces adjacent to it, and

6. Crescent-shaped scars along edges of the channel bank, with their concavities oriented channelward, reflect in junctions with the main channel of small hill slope depressions which direct runoff waters into the main channel.

Davis Creek

Davis Creek is located in western Nelson County, Virginia approximately 30 miles southwest of Charlottesville (Figure 7.21). The entrance to the Davis Creek watershed is 5 miles north of the town of Lovingston, Virginia topographic quadrangle (WCR), 1:62,500 scale.

The watershed encompasses an area of nine square miles. Rocks which underlie the basin are igneous and meta-igneous types and support slopes which are moderately steep to steep. Soils in the area are generally thin on the more steeply sloping land with alluvium and colluvium attaining considerable thicknesses on the lower slopes and within the major channelways.

Rainfall over the watershed was intense during the storm of August 19 and 20, 1969. The deformation of slopes within the

watershed resulting from precipitation runoff associated with this storm was extensive. Since the watershed contained considerable population, damage to property and loss of life were heavy. Practically every channeled hill slope and drainage way within the watershed was affected (Figure 7.25). The debris avalanche represents the dominant mass wastage form found in the study area, although flood plain damage was extensive. In addition, numerous soil slips and other minor forms of mass movement were observed on many normal slopes within the watershed.

The debris avalanche, according to Sharpe (1960), has

> . . . a long and relatively narrow trace, occurs on a steep mountain slope or hillside in a humid climate, and is almost invariably preceded by heavy rains which increase the weight of the unadjusted material and aid in its lubrication.

Hack and Goodlett describe the details of debris avalanching and the development of chutes in the headwaters of North River during a storm which occurred in June, 1949 (Hack and Goodlett, 1960). A similar description of chute development in Nelson County resulting from the storm of August, 1969, is given by Williams and Guy (Williams and Guy, 1971).

The Davis Creek drainage basin is oriented northeast by southwest and is asymmetrical in cross sectional form. Rainfall over the watershed on August 19 and 20, 1969 was extremely intense and much of the total rainfall recorded fell within a period of eight to ten hours (DeAngelis and Nelson, 1969). Peak runoff was reached in the early morning hours of August 20 and damage to hill slopes and channelways occurred at this time. As previously mentioned, damage to hill

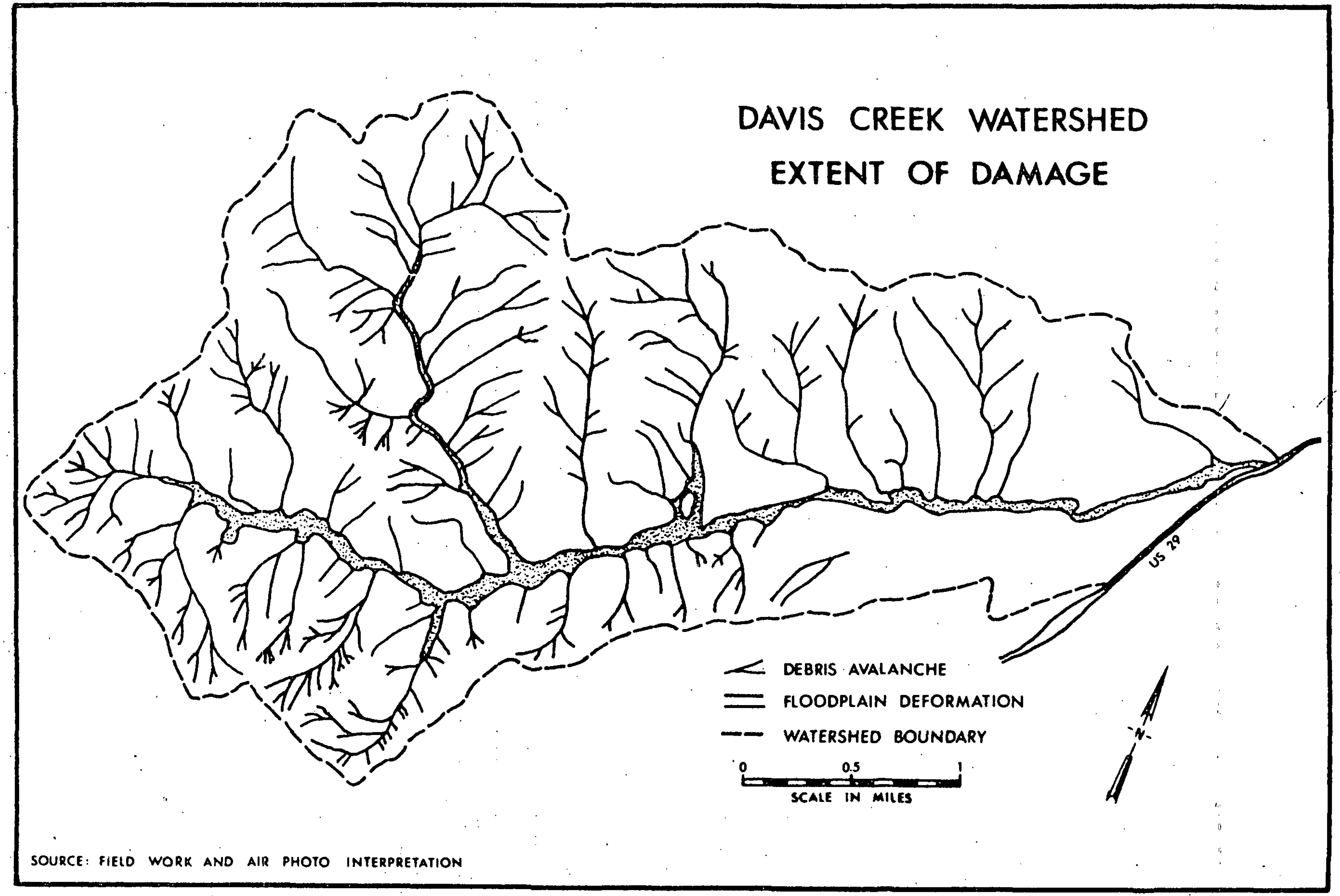


Figure 7.25. Map showing extent of flood damage in Davis Creek Watershed.

slopes and to channelways was severe. The prestorm floodplain of Davis Creek was disrupted throughout its entire length, and coarse debris from collapsed tributary channels was transported considerable distances down the main channelway from their respective tributary junctions.

Collapse of the channeled hill slopes in the Davis Creek watershed resulted in the removal, in practically every case, of both vegetation and residual soil and/or saprolite, leaving the underlying bedrock surface exposed. The exposure of bedrock in these collapsed channelways reflects, in general, the drainage net of the Davis Creek watershed; channel collapse on hill slopes, in other words, was essentially complete. The debris avalanche, which accounted for much of the damage to hill slopes in Davis Creek, is the dominant form of mass wastage found throughout the storm affected area in western Nelson County. The debris avalanches found in the study area vary in geometric form from the single exposed bedrock linear form to multiple branching forms.

Critera developed in this study for the purpose of aiding the interpreter in recognizing and identifying debris avalanches are as follows:

1. The typical debris avalanche is linear in plan, being generally long and narrow,

2. The avalanche scar (chute) most often appears as a surface depression on high angle slopes,

3. Some weathered material may remain on the scoured chute surface,

4. Materials from the debris avalanche may enter established drainage channels and aid in exposing their bedrock floors,

5. The pattern at the head of the chute ranges from a fan-like exposure to one which is serrate, and

6. Extensive debris avalanching is adjusted to the local drainage net, and wide-spread exposures of bedrock on the channel floors delineates clearly the local drainage patterns.

Comparison of Storm Damage in the Two Study Areas

The dominant mass wastage form occurring in Upper Wildwood Canyon is the mudflow, although on the higher slopes within the watershed a few debris avalanche scars were noted. In addition, slumping of colluvial materials was noted at two positions adjacent to the main channel.

In the Davis Creek watershed, the debris avalanche constitutes the dominant mass wastage form. Numerous other forms of mass wastage, however, were noted in the area. These included a variety of soil slips and several slump forms.

The Upper Wildwood Canyon mudflow extends the full length of the drainage basin. Removal of materials was largely confined to the trunk channel, although materials in one tributary were completely removed and in two others partial removal of materials resulted. The trace of the mudflow, however, as reflected by the channelways which show complete or partial collapse of channel materials, define only part of the basin's entire drainage net.

Since the geometric shape of the mudflow is determined by channel position and channel configuration, the photographic pattern of the

mudflow can be described as consisting of a single pattern. Although only a single mudflow occurred in the Upper Wildwood Canyon watershed, the geometric pattern would be modified but slightly had damage to channelways been more extensive. Channel control reflects in the general sinuosity and bifurcated character of the mudflow.

In the Davis Creek area, both slope and channel destruction are so widespread that the trace of damaged channelways, essentially, defines in its entirety the drainage net of Davis Creek. Individual debris avalanches exhibit a variety of patterns since practically all such forms occur in channelways. Sinuous and bifurcated patterns are the rule.

The type of debris transported by mass movement in the respective drainage basins is indicated by the dominant type mass wastage form found in each of the study areas. In Upper Wildwood Canyon the material transported as a mudflow consisted largely of fine sandy alluvium and colluvium. Some coarser rock particles, obviously, were also carried from the headwaters area. Debris transported by debris avalanching in the Davis Creek watershed consisted of both fine soil particles and coarser rock fragments. This is particularly true of the higher channeled slopes, where, in addition to soil and coarse rock detritus, the forest cover was removed. Much of this hill slope material was carried into the main channel of Davis Creek.

Since Upper Wildwood Canyon is more remote from centers of population than is true of Davis Creek, no people occupied the Upper Wildwood Canyon watershed. Hence, no loss of life or damage to

structures resulted. In Davis Creek, however, numerous homes were destroyed and fifty-three persons lost their lives. Most of these lives lost resulted directly from the effects of debris avalanching rather than from floodwaters (Kuhaida, 1971).

Precipitation released over the respective watersheds by the storms, which led to damage of hill slopes and channelways, was unusually high. Although no rainfall data is available for Upper Wildwood Canyon on the day of the storm, January 25, 1969, the Mill Creek intake station recorded fifteen inches of rainfall on this date.* The Mill Creek Canyon drainage basin is located approximately 4.5 miles north of Upper Wildwood Canyon. Rainfall on this magnitude undoubtedly is sufficient for the development of mudflows in the mountains of southern California.

In Davis Creek, record amounts of rainfall were released over the watershed during the storm of August 19, 20, 1969. Up to twenty-seven inches of precipitation were recorded for a twenty-four hour period, with most rainfall occurring during the ten-hour period-- 6:00 p.m., August 19 to 4:00 a.m., August 20 (DeAngelis and Nelson, 1969).

Damage to hill slopes in Upper Wildwood Canyon was minimal. Only four or five slide scars in the study area were seen by this investigator. Damage to the main channel of Upper Wildwood Canyon, however, was extensive. Essentially all of the channel alluvium was removed

*Rainfall data for select stations in areas marginal to the Upper Wildwood Canyon was provided by Mr. William Brooner, Department of Geography, University of California, Riverside.

from the main channel and from a single tributary channel. Damage to both hill slopes and to the main channelway, however, was extensive in the Davis Creek Watershed. Both soil and vegetation was removed from the channeled hill slopes and carried considerable distances down the main channel of Davis Creek. All tributary channels were affected in the Davis Creek watershed, including the smaller "feeder" hollows.

A generalized comparison of the storm-related aspects within the two watersheds is shown in Table 7.4.

Summary and Conclusions

The purpose of this investigation was to compare, through the use of remote sensing imagery, the effects of heavy precipitation runoff on hill slopes and channelways in two widely separated geographical areas. This was accomplished through a description of the dominant mass wastage phenomena occurring in the two areas of study. Standard criteria for recognizing and identifying mass wastage phenomena (mudflows and debris avalanches) were expanded on the basis of signatures from the aerial photographs available for investigation.

Damage to hill slopes was moderate in Upper Wildwood Canyon watershed. Complete removal of channel deposits, however, was accomplished in the main channel and a single tributary. Partial collapse of channel deposits occurred in only three of the remaining tributaries. The dominant mass movement form was a single mudflow.

Damage to hill slopes was moderate in Upper Wildwood Canyon watershed. Complete removal of channel deposits, however, was

TABLE 7.4

COMPARISON OF STORM-RELATED ASPECTS OF UPPER WILDWOOD CANYON AND DAVIS CREEK WATERSHED

Compared Phenomena	Upper Wildwood Canyon	Davis Creek
Dominant mass wastage form	mudflow	debris avalanche
Characteristics of form	channelized; single flow; sinuous in plan bifurcated; single pattern	channelized; multiple debris avalanches; sinuous in plan; bifurcated multiple patterns
Precipitation input	high	abnormally high
Damage to hill slopes	moderate	extensive
Damage to tributary channels	extensive	extensive
Extent of damage	largely confined to main channel	main channel, all tributaries, and all "feeder" hollows
Type of debris transported	alluvium and colluvium	alluvium-colluvium; regolith cover; and forest cover
Structural damage and loss of life	none	severe

accomplished in the main channel and a single tributary. Partial collapse of channel deposits occurred in only three of the remaining tributaries. The dominant mass movement form was a single mudflow.

Damage to hill slopes and to channelways was much more extensive in Davis Creek watershed. Practically every channelway was affected. Large amounts of rock waste, and vegetation, were removed from hill slopes within the drainage basin. The main channel of Davis Creek was congested with the debris from hill slopes. Damage to property and loss of life in the watershed was high. The dominant form of mass movement was the debris avalanche, although numerous minor forms of mass wastage occurred within the basin.

Results from the investigation indicate that considerable information related to mass wastage phenomena can be extracted from aerial photographs.

The criteria developed from photographic images depicted by the available photographs are based largely on pattern, color contrast, and geometric form. Patterns are best reflected in the debris avalanches. Color contrast was helpful in differentiating both forms of mass wastage, but it was particularly useful in differentiating the collapsed channels in the Upper Wildwood Canyon drainage basin from those which were not affected. Geometric form was relied upon most often in recognizing and establishing the identity of debris avalanches.

References

De Angelis, Richard M. and Elmer R. Nelson (1969), "Hurricane Camille, August 5-22," Reprint from Climatological Data, National Summary, XX: 8.

Hack, John T. and John C. Goodlett (1960), Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians, Geological Survey Professional Paper 347, Washington, D.C.: U.S. Government Printing Office.

Kuhaida, Andrew J. (1971), "Debris Avalanching as a Natural Hazard in the Southern Appalachians: A Case Study of the Davis Creek Watershed, Virginia," Unpublished Masters Thesis, Department of Geography, East Tennessee State University.

Poole, Donald H. (1969), The Development of Criteria for Recognizing and Identifying Slope Failure Forms as Depicted by Remote Sensor Returns, Technical Report 12, NASA Contract No. N00014-67-A-0102-0001.

Sharpe, C.F.S. (1960), Landslides and Related Phenomena, Patterson, N.J.: Pageant Books, Inc.

Williams, Garnett P. and Harold P. Guy (1971), "Debris Avalanches--A Geomorphic Hazard," Environmental Geomorphology, Edited by Donald R. Coates, Binghamton: State University of New York.

7.4.4 Barriers To The Diffusion of Remote Sensing Technology

This is an attempt to describe and evaluate the experience of two Los Angeles area governmental agencies with the application of remote sensing technology used to supply information for urban and regional planning. Too often, improvements are made in the state-of-the-art of any technology, and further applications are developed, without respect for constraints many users face applying these innovations. Our objective is to examine how the agencies have used remote sensing, and evaluate their experience and results. Future prospects for application are also identified.

The subject organizations are the Regional Planning Commission (RPC) and Community Analysis Bureau (CAB) of Los Angeles County and City governments. Substantial differences exist in the origin, scope and authority of their functions, their philosophy, and position within the local political milieu (Figure 7.26).

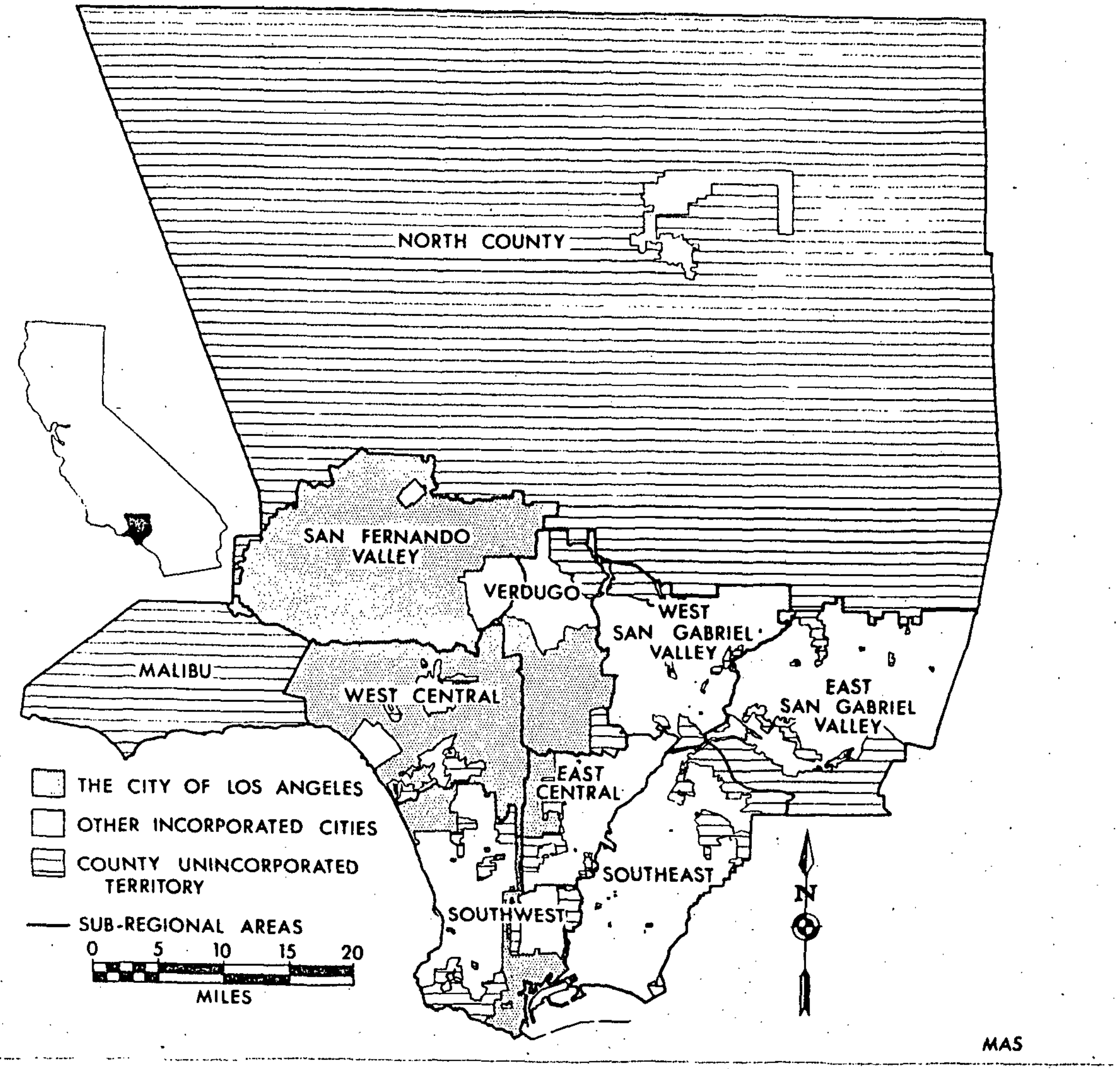


Figure 7.26. Both City and County of Los Angeles agencies serve jurisdictions other than their primary responsibility, the political, city, and unincorporated areas. Contract services are provided on a selective basis, including city planning, to many incorporate cities. Major areas under the exclusive jurisdiction of the County are the sparsely populated Mojave Desert, San Gabriel Mountains (North County sub-region), and Santa Monica Mountains (Malibu sub-region).

The Regional Planning Commission

The Regional Planning Commission administers zoning and subdivision codes for the 1.1 million populated unincorporated area of Los Angeles County (3,020 of the county's 4,083 square miles, largely an urban fringe, vacant, desert and mountain landscape without many urbanized areas), and prepares general plans and specialized studies for the entire county including incorporated cities. State Planning Law relegated to county planning agencies the functions of planning unincorporated areas and coordinating cities on broad scale problems. Regional in name alone, its functioning became constrained and complemented by a multiplicity of organizations which also do planning. Seventy-six incorporated cities besides Los Angeles, with 3.2 additional million persons, comprise the remainder of the county. These cities, an array of special districts, other county departments, and Federal and State agencies, totalling nearly 500 entities, have divided the planning function into a complex pattern. Transportation agencies do transportation planning; water agencies do water planning. This level of fragmentation has so divided the regional planning responsibilities as to make it virtually impossible for one organization to function successfully. As planning processes broaden to encompass regional scales, the scope of authority to implement planning weakens. Jurisdictional fragmentation and the desire for "home rule" are at fault. Each political entity guards its development right and control. By default, RPC deals with planning the land use of less-structured areas on the urban fringe through zoning and subdivision codes.

Remote Sensing at RPC

Remotely sensed data has been used at the RPC sporadically for nearly 50 years, particularly in the post World War period when the region experienced its remarkable surge of growth. A vast array of site-scale planning decisions had to be made within the framework of the zoning and subdivision codes. Some of these decisions (a small fraction) were made using oblique and vertical black-and-white photographs usually submitted by property developers. The tendency was, however, to base most decisions on field survey data and testimony obtained at public hearings. Aerial photography did not replace traditional ground survey methods of data gathering, but it could and did serve as an adjunct to them.

In the late 1950's, remote sensing was applied in the same intermittent, adjunct fashion to long range planning problems involving areas larger than the site scale. Large scale photos and photo mosaics were first used as primary land use data sources during the mid-1960's in the San Fernando and San Gabriel Valley planning studies. Ten years of experience (1955-65) led to greater reliance on remote sensors, but this reliance did not extend to acquiring imagery on a regular basis.

Since 1965, the use of aerial photography increased considerably. Black-and-white photographs were used for the largest county subregion (North County) due to the infeasability of ground survey. More significant was the application of larger scale aerial photographs to small "community" plan projects of unincorporated areas, and to special, thematic studies of agriculture and other systematic topics.

In 1969, RPC initiated its own contract and acquired color infrared aerial photographs (Type 8443), at a scale of 1:24,000, for a county-wide land use survey. In the 1970's the emphasis on remote sensing continued to shift from larger to smaller, county-wide, photo scales. Satellite imagery has been employed in public presentations of the county-wide program. In 1971, General Electric Corporation approached the RPC suggesting a joint proposal to NASA to evaluate the possible application of satellite imagery, obtained from the ERTS-A (ERTS-1) program, to urban planning.

The Community Analysis Bureau

CAB was formed in 1967 as a separate unit of the city government of Los Angeles, funded by a Community Renewal Programming grant from the Department of Housing and Urban Development (HUD) for two-thirds of its costs. The broad goal of CAB is to prepare a citywide program of community improvement designed to correct existing and deter future blight and obsolescence.

CAB has been authorized to develop a comprehensive information storage and retrieval system which will, in theory, provide effective and timely information to assist on-going city operations--especially planning and decision making.

Local governments, the Los Angeles area being no exception, have generally been reluctant to implement the concepts owing to their cost, both in terms of research and programs. While funds are available from outside sources, many cities hesitate to accept them. Performance criteria associated with Federal monies are contrary to a (jealously

protected) "home rule" tradition. Social unrest in many central cities (again, the Los Angeles area being no exception) provided crises that are changing these attitudes.

Origin, Objectives, and Role -- CAB exists solely to innovate, a task planning agencies cannot afford to do themselves, and operates because of federal encouragement to modernize planning functions. By nature of its assignment, CAB deals with traditionalism daily while integrating varied data files in order to pursue its innovative task. With indirect involvement in decision-making, CAB operates relatively free of local political influence except for the city's share of support where they are vulnerable and expendable, like most research agencies. The problem is that they are not bureaucratic enough, and lack built-in tendencies for self-preservation owing to the short-term and terminal assignment, and to the city's tenuous support.

Organization and Methodology -- Innovativeness requires CAB to relate closely to modern research agencies not only in remote sensing technology but through computer technology, mathematics, and the social sciences. Their information chain ranges widely. They rely on traditional agencies for data but not for methodological and conceptual stimuli.

Underlying these differences is the scope and philosophy which is fundamental to CAB's purpose. "Social" planning strives to compensate for the failure of "physical" planning: to resolve major issues in welfare and problems concerning the human element. Over the years, planners tried to integrate the two philosophies with little success.

Developments in remote sensing techniques enable data to be acquired systematically and economically over large areas. A geographic information system marries the two technologies in a fashion that simplifies "physical" planning information needs and offers techniques which greatly reduce the information demands of "social" planners.

Remote Sensing at CAB -- CAB applies a systems approach to its task. A comprehensive information storage and retrieval system necessitates the integration of varied data sources within the city into one overall system. Experience has shown that if geographic data can be spatially identified it can provide an effective tool for the decision-making process. Since geographic data is seldom static, the information system should be able to produce continuously updated information in quantity, permit periodic evaluations of conditions and trends in the city, allow statistical methods of analysis, and have the capacity for various types of data handling. Then, implications of decisions can be traced by their interaction with other elements of the system. When fully developed, the information system, called LUPAMS (Land Use Plan Analysis Management System), proposes to collect, machine-store, and produce data at the block level. Ideally, information will be tailored to the needs of planners and be available to the largest number of agencies at minimum cost. Large scale (1:10,000) color infrared aerial photographs were recently acquired covering the city and surrounding areas. Steps are being taken to fully integrate remote sensing in an on-going monitoring system that will record housing quality data (the only remotely sensed data currently used) annually at larger scales (1:5,000) for the city's poorer areas.

Factors Acting As Barriers

Planning agencies at the local level represent a large body of potential users of remote sensing technology. Spatial data in great volumes can be obtained inexpensively by aerial photography. This data can be collected, extracted for various purposes, and stored for further use and historical record more easily, consistently, objectively, and at lower unit cost than traditional ground-based methods. It is important to clarify why more agencies have not adopted this research tool and why RPC and CAB have adopted it, if differently.

Leaders, who may be individuals or groups acting as individuals, determine information flow; from what sources it originates, how it is modified, and what purposes it serves. In the case of planning procedures, these leaders represent a greater society--the cultural milieu in which planning goals and philosophy are defined. This milieu consists largely of a political context that involves planning "publics," where a smaller society--the planning agency--is assigned leadership once goals are defined. The smaller agency, in turn, is lead by the top management level. A primary problem is that decision-makers have lost touch with the less-involved majority of the population by relying on the political process and persons concerned with planning (developers, builders, and occasional antagonized citizens). Varied influences come from outside the agency, but those which have maximum impact are extremely local.

Another problem arises because RPC relies on various interdepartmental contacts with the county governmental system where the same

local context with similar responsibilities has evolved producing a closed circle of members stimulating and responding to each other. Contacts with traditional agencies, and the lack of such contact with dissimilar agencies (the CAB and RPC have offices two blocks apart), reduces the input of varied information.

Judgements, values, notions, attitudes, and opinions form a collective frame of reference against which every society measures decisions. Built-in tendencies, to preserve and maintain the status quo and the integrity of past experience, result in a propensity to set up barriers against change. Organizations with these tendencies have been identified as having a traditional orientation.

RPC is a traditional agency. It has built in tendencies toward long concentrated manpower and budgets on current planning or the administration of land use regulations. In so doing, planning came to represent specialized needs and a unique land development history. New traditions are developing under the influence of a reduced need for current planning, the pressure of planning legislation, and changes in the planning profession, but changes come very slowly.

Ideally, a remote sensing system would provide wide regional coverage of inaccessible or sparsely monitored geographic information. Such a system is particularly useful for recording those data that are ephemeral or highly mobile. A geographic information system using the synoptic and planimetric qualities of aerial photography has limited utility to site-oriented problems. This is a limitation of research design, not equipment capability. Sophisticated equipment

to obtain and process data is practically useless unless one carefully considers the data items themselves, their use, and the design of computer retrieval capabilities. The problem is perpetual. Traditional planning requires information well within the procurement capabilities of remote sensing, but there is little understanding of that capability and even less demand for a more modern form of planning that would require the full potentials of remote sensing techniques.

Several distinctions must be made. The circumstances under which CAB was formed, its definition of objectives, those who define its objectives, its role in planning, position in the local political hierarchy, source of funding, and duration of work will differ from RPC and other planning agencies. Consequently, its organization and methodology evolved under unique conditions and bear no relationship to a traditional agency.

These two organizations provide extreme examples of the use of remote sensing; as one of the data inputs in an information system, and as an illustrative, supplemental, and occasionally primary source of information for every-day planning operations. Remote sensing has potential beyond CAB's present use (housing quality). It can be applied as an information system that monitors and observes many qualitative parameters in the environment. RPC has made more varied uses of remote sensing, but the level of reliance upon and integration of this data in planning programs is far from complete. It remains an intermittent, piecemeal, weakly conceived graft onto a persistent manual technology of land use analysis that is "cosmetic" in nature

and which is used to "tidy-up" after studies are done by other methods.

Recommendations

1. Remote sensing techniques should be incorporated into a systems approach for full utilization.

2, Personnel should be trained in the acquisition and application of remotely sensed data.

3. Fragmented governmental research functions should be consolidated and pooled to eliminate duplicate efforts and to accumulate both the demand and capital outlay necessary to justify modernizing an information system.

4. Opportunities should be provided for practical demonstrations at workshops, schools of planning, and symposia for contact between scientists and users. An information disseminating system could be developed addressed to key personnel in user agencies and interested personnel at lower ranks. This information must transcend the language barrier between scientists and users.

Prospect

Considerable potential for uses of remote sensing techniques exist in advance planning procedures. Problems are many. Not all of the advantages of remote sensors are fully appreciated. Misapplications in the past have led many agencies to doubt the utility of remote sensors. The fault lies with an inability to justify special flights necessary for best results (e.g., temporally adjusted with census taking, or technically precise) for imagery used only for land use

data. Site-orientation plagues advance planners to the degree that land use data for large areas are collected by field survey. Another problem is that plans are seen as terminal, twenty-year forecasts of land use without a concept of phased land development, and involving only objective environmental criteria. Essentially ,the difficluty is a restricted concept of advance planning. With pressure all around for modernizing the methodology and broadening the scope, however, there is hope for change. Remote sensing offers distinct and unique advantages dealing with environmental issues where policies must be based on qualitative data. It permits the establishment of standard or universal observations and criteria for change. Such observations at frequent intervals reveal precursors of change and trends where one can search for root questions or determine probabilities. It permits continuous planning (monitoring, updating, surveillance of hazards) at regional scales. Also, aeiral photography presents the total visual universe of data (depending on resolution) which can be stored as a spatially precise record, unbiased by the investigator's experience. These advantages suggest uses for remote sensing in a different sort of planning than is practiced today.

One way traditional agencies have made rapid changes is through crises. Although there are many which are potentially as severe, county planners have lacked crises comparable to the social unrest experienced by many central cities. Such crises weaken the heirarchical structure and decision-making processes flounder. These events tend to modify the agency outlook.

Urban and suburban problems and demands on planners have increased, but their solutions have become complicated as well. Any technology such as remote sensing that simplifies day-to-day procedures and operations will be essential. The crises in traditional agencies have not been severe enough to effectuate change. It is unfortunate that public agencies must face near-disaster before realizing the need to innovate.

7.5 FUTURE STUDY

Efforts at the Riverside campus for the next year will be directed toward: (1) development of a computer-based Geographical Information System to include refinement of our computer mapping systems, (2) expansion of our study area to include the western portion of the California Desert, and (3) continued study of the impact on the environment of the southern California coastal basin caused by the importation of water from the California Water Project.

Data produced as a result of the various studies under the Integrated Study are being stockpiled at an ever-increasing rate. The ultimate objective of determining the impact of newly imported water into southern California will be difficult to achieve if these data are not organized into some type of logical information system. The development of computer programs to produce computer maps has been aimed at arranging the data in some logical order, but only for single categories of data. Our effort in the coming year will be directed toward developing a more flexible Geographic Information System for southern California in which more than one category of data can be correlated and reproduced both statistically and

graphically. A basic problem with the design of a universal information system is the use of a "polygon overlay system" versus a "grid-matrix system" to provide geographical location for area data. The grid matrix is a less complex system for computer performed correlations, but the data input is a laborious manual process and the output is a graphic display which is a not so elegant grid map produced by symbols on the line printer. The polygon overlay system becomes a very complex computer problem when several different categories of information are being correlated, but the locational accuracy of the data is much greater and the graphic output resembles a true cartographic map. We propose to resolve the problems of both systems this coming year by designing a hybrid of the two systems, thus providing the greatest flexibility for an information system.

Refinement in our computer mapping systems is required to keep pace with the development of the Geographical Information System. The present maps developed to monitor change in the Riverside-San Bernardino-Ontario area are excellent qualitative maps for a single time period evaluation. However, the need is for quantitative mapping of the same area with rapid capability to statistically summarize the total area involved in each land use category and to indicate the areal change of each category between two time periods. It is proposed that UCR continue to refine the computer mapping systems for thematic map use and to provide more statistical flexibility.

The availability of an information data base will provide the ability to continue the water impact studies in such areas as the

Perris Valley. Change in agricultural practices will be monitored with the arrival of water in Lake Perris in May 1973. Correlation of changes in land use patterns can be correlated with other factors such as economics, population, land values, etc..

The receipt of ERTS imagery along with the high altitude U-2 ERTS underflight imagery has now made it practical for the Riverside campus unit to expand the study area to the western portion of the California Desert. The area includes Antelope Valley, Mojave River Valley, and Lucerne Valley. The importation of water in these three areas is already making an impact in many activities including agriculture, recreation, sub-division, industrial sites, and energy production. Disturbances of the natural landscape has become a critical problem in the desert and immediate study of the impact on the desert environment resulting from both human and natural causes is essential in order for county, state and federal land planners and resource managers to make decisions on future uses of the desert. It is proposed that UCR expand the study area to the western portion of the California Desert.

The passage of Proposition 20 (environmental control of the use of the California coastline) during the last election makes our integrated studies along the California coast exceedingly important. We anticipate continuing the coastal basin studies, also, to develop data which can be used by the various regional coastal areas. The environmental studies along the coastal basins are providing the county planners considerable data to help make decisions regarding

the use and preservation of open spaces. The coastal basin studies are providing, and will continue to provide, considerable information on the phenomena involved with the transition of land from rural use to urban use.

7.6 PUBLICATIONS

The following is a list of the works published by participants in the research effort at UCR since 1972. These have been divided into three categories: (1) published works; (2) papers presented; and (3) reports and papers in preparation for publication.

7.6.1 Papers and Reports Published

1. Pease, S. R. and R. W. Pease, "Photographic Films as Remote Sensors for Measuring Albedos of Terrestrial Surfaces," March 1972, Tech Report V.

2. Pasqualetti, M. J., "Land Use Survey by Remote Sensing and Computer Mapping," May 1972.

3. Minch, J.A., "Landsliding and the Effects of Resort Development Between Tijuana and Ensenada, Baja California, Mexico," in Coastal Studies in Baja California, June 1972, Tech Report 0-72-1.

4. Coleman, V., "Ground Survey and Air-Photo Analysis of the Llano de San Quintin, Baja California del Norte, Mexico," in Coastal Studies in Baja California, June 1972, Tech Report 0-72-2.

5. Bale, J.B., "Landscape Analysis of the Punta Canoas Region: Baja California del Norte, Mexico," in Coastal Studies in Baja California, June 1972, Tech Report 0-72-3.

6. Gilman, H. F., "Regionalization of Land Use Along the West Coast of the Estado de Baja California, Mexico," in Coastal Studies in Baja California, June 1972, Tech Report 0-72-4.

7. McDonald, D. B. and R. E. Snead, "Comparison of Aerial Photographs of the San Felipe Region, Baja California," in Coastal Studies in Baja California, June 1972, Tech Report 0-72-5.

8. Poole, D. H., "Studies in Physical Geography: The Deformation Characteristics of Hill Slopes and Channelways in Two Different Environments as Depicted by Remote Sensor Returns," August 1972, Tech Report T-72-1.

9. Goehring, D. R. and J. S. McKnight, "Barriers to Innovation: The Example of Remote Sensing in Urban and Regional Planning in the Los Angeles Metropolis," September 1972, Tech Report T-72-2.

10. Nichols, D. A. and W. G. Brooner, "Interfacing Remote Sensing and Automated Geographic Information Systems," September 1972, Tech Report T-72-3.

11. Bowden, L. W., "Remote Sensing of the World's Arid Lands," Coastal Deserts: Their Natural and Human Environments, University of Arizona Press, Tucson, Arizona, 1972.

12. Bowden, L. W., "Remote Sensing of Southern California: An Experiment to Inventory a Region," Proceedings: Symposium on Remote Sensing of the Environment, Council of Scientific and Industrial Research, Pretoria, May 1972.

13. Bowden, L. W., "How to Define Neighborhood," The Professional Geographer, XXIV(3), August 1972.

14. Bowden, L. W. and C. W. Johnson, "A Recipe for 'Do-it-Yourself' Color Composites of ERTS-1: The Poor Man's Guide to Everlasting Color," Proceedings: International Conference on Remote Sensing in Arid Lands, University of Arizona, Tucson, November 1972.

15. Bowden, L. W., "Assessment of the Impact of the California Water Project in Southern California," An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques, Space Science Laboratory, University of California, Berkeley, Annual Progress Report, NASA Grant NGL 05-003-404, May 1972, 70 pp.

16. Bowden, L. W. and H. Aschmann, "Remote Sensing of Environmental Quality: Problems and Potential," in Readings in Remote Sensing: Techniques for Environmental Analysis, J. E. Estes and L. W. Senger, Eds. Hamilton Press, in press.

17. Bowden, L. W. and J. B. Bale, "Land Use in the Northern Coachella Valley," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973.

18. Bowden, L. W. and J. H. Viellenave, "Assessment of Southern California Environment from ERTS-1," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973.

19. Bailey, H. P. and C. W. Johnson, "Potential Evapotranspiration in Relation to Annual Waves of Temperature," International Geography, Papers of the 22nd International Geographical Congress, 1972, Montreal, Canada, pp. 131-133.

20. Johnson, C. W., "Design of A Computer-Oriented Agricultural Land Use Mapping System," Geographical Data Handling, 1972, A Publication of the International Geographical Union Commission on Geographical Data Sensing and Processing, Ottawa, Canada, pp. 588-600.

21. Johnson, C. W. and V. B. Coleman, "Semi-Automatic Crop Inventory From Sequential ERTS-1 Imagery," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard SFC, Greenbelt, Maryland, March 5-9, 1973, 8 pp.

22. Pease, R. W. and C. W. Johnson, "New Fault Lineament in Southern California," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard SFC, Greenbelt, Maryland, March 5-9, 1973, 6 pp.

23. Coleman, V. B. and C. W. Johnson, "Evaluation of Remote Sensing in Control of Pink Bollworm," Symposium on Significant Results Obtained From ERTS-1 NASA/Goddard SFC, Greenbelt, Maryland, March 5-9, 1973, 6 pp.

7.6.2 Papers Presented

1. Bowden, L. W., "Remote Sensing and Urban Analysis," Invitational Paper, University of Hawaii, February 1972.

2. Bowden, L. W., "Remote Sensing of the Environment," Invitational Paper, New Zealand Cartographic Society, Wellington, February 1972.

3. Bowden, L. W., "Remote Sensing as a Geographic Aid," Invitational Paper, University of Canterbury, Christchurch, New Zealand, February 1972.

4. Bowden, L. W., "Remote Sensing of the Environment with Geographic Applications," Invitational Paper, University of Queensland, Brisbane, March 1972.'

5. Bowden, L. W., "The California Water Plan," Invitational Paper, University of New England, Armidale, New South Wales, March 1972.

6. Bowden, L. W., "Remote Sensing as a Geographic Tool," Invitational Paper, University of New England, Armidale, New South Wales, March 1972.

7. Bowden, L. W., "Remote Sensing with Multi-Spectral Techniques," Invitational Paper, University of Newcastle, New South Wales, March 1972.

8. Bowden, L. W., "Remote Sensing for Australian Planners," Invitational Paper, University of Newcastle, New South Wales, March 1972.

9. Bowden, L. W., "Remote Sensing: A Geographic Tool," Invitational Paper, University of Newcastle, New South Wales, March 1972.

10. Bowden, L. W., "Color Infrared Photography for Urban Investigation," Invitational Paper, University of New South Wales, Sydney, March 1972.

11. Bowden, L. W., "Remote Sensing and Its Role in Cartography," Invitational Paper, University of New South Wales, Sydney, March 1972.

12. Bowden, L. W., "Remote Sensing of Biogeographic Environments," Invitational Paper, Australian National University, Canberra, March 1972.

13. Bowden, L. W., "Remote Sensing and It's Future in The Earth Sciences," Invitational Paper, Australian National University, Canberra, March 1972.

14. Bowden, L. W., "Remote Sensing and Forestry," Invitational Paper, University of Melbourne, April 1972.

15. Bowden, L. W., "Urban Analysis with Remote Sensing," Invitational Paper, University of Monash, Victoria, April 1972.

16. Bowden, L. W., "Remote Sensing of the Environment," Invitational Paper, University of Tasmania, Hobart, April 1972.

17. Bowden, L. W., "Remote Sensing as a Geographic Tool," Invitational Paper, University of Tasmania, Hobart, April 1972.

18. Bowden, L. W., "Remote Sensing of the Urban Environment," Invitational Paper, University of Adelaide, South Australia, April 1972.

19. Bowden, L. W., "Remote Sensing for Urban and Regional Planning," Invitational Paper, University of Flinders, South Australia, April 1972.

20. Bowden, L. W., "Remote Sensing for Urban and Regional Planning," Invitational Paper, University of Western Australia, Perth, April 1972.

21. Bowden, L. W., "Remote Sensing as a Geographic Tool," Invitational Paper, University of Cape Town, April 1972.

22. Bowden, L. W., "Remote Sensing of the Environment," Invitational Paper, University of Stellenbosch, Cape Province, April 1972.

23. Bowden, L. W., "Remote Sensing of the Environment," Invitational Paper, University of Orange Free State, Bloemfontein, April 1972.

24. Bowden, L. W., "Remote Sensing as a Geographic Tool," Invitational Paper, University of Witswatersrand, Johannesburg, May 1972.

25. Bowden, L. W., "Remote Sensing of Southern California: An Experiment to Inventory a Region," Invitational Paper, Symposium on Remote Sensing of the Environment, CSIR, Pretoria, May 1972.

26. Bowden, L. W., "Remote Sensing of the Environment," Invitational Paper, University of Ibadan, Nigeria, May 1972.

27. Bowden, L. W., "The Potential for Using Spacecraft Imagery for Wild Animal Inventory," Invitational Paper, Kruger National Park Research Station, May 1972.

28. Bowden, L. W., "A Recipe for 'Do-It-Yourself' Color Composites of ERTS-1: The Poor Man's Guide to Everlasting Color," International Conference on Remote Sensing in Arid Lands, University of Arizona, Tucson, November 1972.

29. Bowden, L. W. and J. B. Bale, "Land Use in the Northern Coachella Valley," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973.

30. Bowden, L. W. and J. H. Viellenave, "Assessment of Southern California Environment From ERTS-1," Symposium on Significant Results Obtained From ERTS-1, NASA/Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973.

31. Gilman, H. F., "Regionalization of Land Use Along the West Coast of Baja California," California Council of Geographic Education, Pasadena, May 1972.

32. Huning, J. R., "A Preliminary Examination of Changing Visibility at Los Angeles International Airport, 1947-1967," California Council of Geographic Education, Pasadena, May 1972.

33. Johnson, C. W., "Rural and Agricultural Land Use Mapping From Remote Sensing," UNESCO/IGU Second Symposium on Geographical Information Systems, Ottawa, August 1972.

34. Johnson, C. W. and H. P. Bailey, "Potential Evapotranspiration and Annual Waves of Temperature," Thornthwaite Memorial Session, 22nd International Geographical Congress, Montreal, August 1972.

35. Johnson, C. W., "Coastal Land Use Automated Mapping Systems," Office of Naval Research Program Review, Washington, D.C., June 1972.

36. Johnson, C. W., "Remote Sensing from Satellites," Sigma XI Chapter, California State University, Fullerton, May 1972.

37. Viellenave, J. H., J. E. Estes and L. W. Senger, "Agricultural Developments on the West Side of the San Joaquin Valley," Arizona Academy of Science Annual Meetings, Flagstaff, May 5-6 1972.

38. White, K. L., "A Preliminary Investigation of Climatic Change in Middle North America, 1890-1960," California Council of Geographic Education, Pasadena, May 1972.

7.6.3 Papers in Preparation

1. Viellenave, J. H., The Roles of Recreation Sites and Environmental Homesite Desirability in Modifying Land and Property Values, Tech Report in manuscript form.

2. Huning, J. R. and R. M. Petersen, Use of Yucca brevifolia as a Surrogate for Detection of Near-Surface Moisture Retention, Tech Report in manuscript form.

3. Bale, J. B. and J. H. Viellenave, "The Use of Remote Sensing Techniques in Management and Planning of Recreational Areas," for Manual of Remote Sensing, L. W. Bowden, editor.

APPENDIX I

TABLE 1

POST MISSION 164 U-2 PLATFORM

Accession Number	Sensor ID Number	Flight Number	Date	Area
		70 mm Format		
00005	001	71-025	9-1-71	Southern California Test Site
00006	002	"	"	
00007	003	"	"	"
00008	004	"	"	"
00041	002	71-036	9-24-71	"
00042	003	"	"	"
00043	004	"	"	"
00058	001	71-048	10-14-71	"
00059	002	"	"	"
00060	003	"	"	"
00061	004	"	"	"
00116	001	71-067	11-24-71	"
00117	002	"	"	"
00118	003	"	"	"
00119	004	"	"	"
00140	001	71-075	12-9-71	"
00141	002	"	"	"
00142	003	"	"	"
00143	004	"	"	"
00194	001	72-020	2-3-72	"
00195	002	"	"	"
00196	003	"	"	"
00197	004	"	"	"
00198	001	72-024	2-17-72	"
00199	002	"	"	"
00200	003	"	"	"
00201	004	"	"	"

TABLE 1 continued

Accession Number	Sensor ID Number	Flight Number	Date	Area
00214	001	72-035	3-3-72	Southern California Test Site
00215	002	"	"	
00216	003	"	"	"
00217	004	"	"	"
00248	001	72-049	3-28-72	"
00251	004	"	"	San Francisco Bay
00264	001	72-054	3-31-72	Southern California Test Site
00265	002	"	"	
00266	003	"	"	"
00267	004	"	"	"

9" x 9" Format

Accession Number	Sensor ID Number	Flight Number	Date	Area
00460	017	72-101	6-16-72	Mojave Desert
00498	"	72-112	7-11-72	Southern California Test Site
00575	"	72-130	8-1-72	
00760	016	72-178	10-11-72	Los Angeles
00772	017	72-185	10-24-72	Imperial Valley/Yosemite
00818	016	72-201	11-21-72	Barstow/Las Vegas
00866	017	72-216	12-19-72	Imperial/Coachella Valley
00867	017	72-217	12-20-72	Barstow/Las Vegas

APPENDIX I

TABLE 2A

ERTS FRAME SUMMARY BY PERIOD - 1972-1973

9.5 Inch Positive

CYCLE	1	2	3	4	5	6	7	8	9	10	11
Frame											
1						11/5		12/11			
2			9/12			11/5	11/23	12/11	12/29		
3	8/7	8/25	9/12	9/20		11/5	11/23	12/11	12/29		
4	8/7						11/23		12/29		
5						11/5	11/24	12/12	12/30		
6		8/26	9/13	10/1		11/6	11/24	12/12	12/30	1/17	
7		8/26	9/13	10/1		11/6	11/24	12/12	12/30	1/17	
8				10/1			11/24		12/30	1/17	
9							11/25	12/13	12/31	1/18	
10			9/14	10/2			11/25	12/13	12/31	1/18	
11			9/14			11/7	11/25	12/13	12/31	1/18	
12									12/31	1/18	
13											
14	8/10					11/8	11/26	12/14	1/1	1/19	
15	8/10		9/15			11/8	11/26	12/14	1/1	1/19	
16				10/3		11/8		12/14	1/1	1/19	
17	8/11					11/9	11/27		1/2	1/20	
18		8/29		10/4	10/22	11/9	11/27	12/15	1/2	1/20	
19							11/27	12/15	1/2	1/20	
20								12/16	1/3	1/21	
A-1							11/22				
A-2							11/22	12/10	12/28		2/2
A-3									12/28	1/15	2/2

APPENDIX I

TABLE 2B

ERTS FRAME SUMMARY BY PERIOD - 1972-1973

70 mm Positive

CYCLE	1	2	3	4	5	6	7	8	9	10	11
Frame											
1						11/5		12/11			
2						11/5	11/23	12/11	12/29		
3						11/5	11/23	12/11	12/29		
4							11/23		12/29		
5						11/6	11/24	12/12	12/30		2/4
6						11/6	11/24	12/12	12/30	1/17	2/4
7						11/6	11/24	12/12	12/30	1/17	2/4
8							11/24		12/30	1/17	2/4
9							11/25	12/13	12/31	1/18	
10							11/25	12/13	12/31	1/18	
11						11/7	11/25	12/13	12/31	1/18	
12									12/31	1/18	
13											
14						11/8	11/26	12/14	1/1	1/19	
15						11/8	11/26	12/14	1/1	1/19	
16						11/8	11/26	12/14	1/1	1/19	
17						11/9	11/27		1/2	1/20	
18						11/9	11/27	12/15	1/2	1/20	
19							11/27	12/15	1/2	1/20	
20								12/16	1/3	1/21	
A-1											
A-2							11/22	12/10	12/28		2/2
A-3									12/28	1/17	2/2

APPENDIX I

TABLE 2C

ERTS FRAME SUMMARY BY PERIOD - 1972-1973

70 mm Negative

CYCLE	1	2	3	4	5	6	7	8	9	10	11
Frame											
1						11/5		12/11			
2						11/5	11/23	12/11	12/29		
3	8/7	8/25	9/12	9/30		11/5	11/23	12/11	12/29		
4	8/7						11/23		12/29		
5						11/6	11/24	12/12	12/30		2/4
6		8/26	9/13	10/1		11/6	11/24	12/12	12/30	1/17	2/4
7		8/26	9/13	10/1		11/6	11/24	12/12	12/30	1/17	2/4
8				10/1			11/24		12/30	1/17	2/4
9							11/25	12/13	12/31		
10			9/14	10/2			11/25	12/13	12/31		
11			9/14			11/7	11/25	12/13	12/31		
12									12/31		
13											
14	8/10					11/8	11/26	12/14	1/1	1/19	
15			9/15			11/8	11/26	12/14	1/1	1/19	
16				10/3		11/8		12/14	1/1	1/19	
17	8/11						11/27		1/2	1/20	
18		8/29		10/4	10/22		11/27	12/15	1/2	1/20	
19								12/15	1/2	1/20	
20								12/16	1/3	1/21	
A-1											
A-2							11/22	12/10	12/28		2/2
A-3									12/28	1/17	2/2

APPENDIX II

INFORMATION AND APPLICATIONS ASSISTANCE

I. Origin of Visitor

A. Academic

1. Faculty

a) University of Montana

b) University of California, Riverside

c) University of Wisconsin

d) University of Southern California

e) California State University, Fullerton

f) San Diego State University

g) University of California, Los Angeles

h) Cal Poly, Pomona

i) University of California, Santa Barbara

j) Rio Hondo Junior College

k) San Bernardino Valley College

l) Riverside City College

m) Pierce Junior College

2. Students

a) UCR (Anthropology, Geology, Business Administration, Sociology, Political Science, Biology, Plant Sciences, Soils, Urban Studies, and Dry Lands Institute)

b) UCLA (Geography, Architecture & Urban Planning)

c) California State University, Fullerton (Geography, Anthropology)

d) California State University, San Diego (Geology)

B. Government Agencies

1. City

a) Department of Water and Power, Los Angeles

b) Department of Parks and Recreation, Los Angeles

c) Riverside City Planning Department

2. County

a) Los Angeles County Planning Department

b) Los Angeles County Parks and Recreation

c) Riverside County Planning Department

d) San Bernardino County Planning Department

e) Orange County Planning Department

3. State

a) Department of Water Resources

b) Department of Highways

c) Department of Parks and Recreation

4. Federal

a) Bureau of Land Management

b) NASA (Goddard)

c) Bureau of Reclamation

d) USDA

C. Private

1. Southern California Testing Labs
2. Davidson Engineering
3. Doubleday and Company
4. Los Angeles Times
5. Environmental Systems Research Institute

II. Types of Assistance

A. Philosophy and Uses

B. Introduction to Remote Sensing Technology

C. Sensors and Processing

D. Techniques and Methods

E. Automated Interpretation and Mapping

F. Classroom and Instructional Aids

G. Bibliographic Aid

H. Subjects Analyzed

1. Land Use
2. Natural Vegetation and Wildlife Habitat
3. Geomorphology
4. Urban Growth
5. Environmental Impact Studies
6. Real Estate Development
7. Recreation
8. Statistics on Newcastle Disease

9. Regional Planning

10. Environmental Hazards

11. Environmental Perception

I. Coordination on Projects (BLM on-off road vehicle analysis)

N74-14013

Chapter 8

DIGITAL HANDLING AND PROCESSING OF REMOTE SENSING DATA

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8.1 INTRODUCTION

An important part of the integrated study of Earth Resources carried out by the University of California is the combined use of all available sensing devices which provide information of interest to earth resource scientists. Two considerations influence the use of multisensor data. Firstly, the data collected in each of several different bands on each of several different dates need to be analyzed in various combinations. Secondly, with the launch of the ERTS 1 Satellite, sets of multisensor data in an electronic format have become available to the project as one of the major data sources. Thus a significant component of our work is the efficient or optimal use of the large amount of data available which has bearing on the study of specific earth resources. Three approaches are used in the analysis of the available data:

Human Photo Interpretation

Electronic Image Enhancement

Automatic Data Processing

These three approaches complement one another and are all pursued within

our study. In order to articulate and understand these different approaches we show in Figure 8.1 a block diagram of the acquisition, analysis, and enhancement of remote sensing imagery. For each of the features of interest a set of attributes, $\underline{Y}$, makes it possible to study this feature from remote sensing imagery. By the time the attributes of the feature of interest have been recorded, in block 3, as spectral images or scans, these attributes have been modified by several partially known or unknown effects. These effects will include, for instance, the mixing of features due to insufficient image resolution, the variations of sunlight illumination, and degradation due to atmospheric scattering and turbidity. The analysis of the resulting imagery will be affected to various degrees by all of these poorly known effects. In some cases, such as the mapping of rangeland resources, the task can be done conveniently by considering a single spectral image or a standard color combination of spectral images. In other cases, such as monitoring water quality, the task is sufficiently more difficult that more sophisticated analysis techniques are needed. In its generality, the study of ground features from remote sensing data falls within the framework of statistical decision and estimation theory. The study of spectral and other properties of surfaces is now called the acquisition of *a priori* information. The transformation of the attributes of the feature of interest into attributes of the images or scan is a probabilistic mapping. Thus, for a given feature of interest the recorded attributes have a statistical distribution which has to be taken into account in studying this feature. The number of images or scan can be

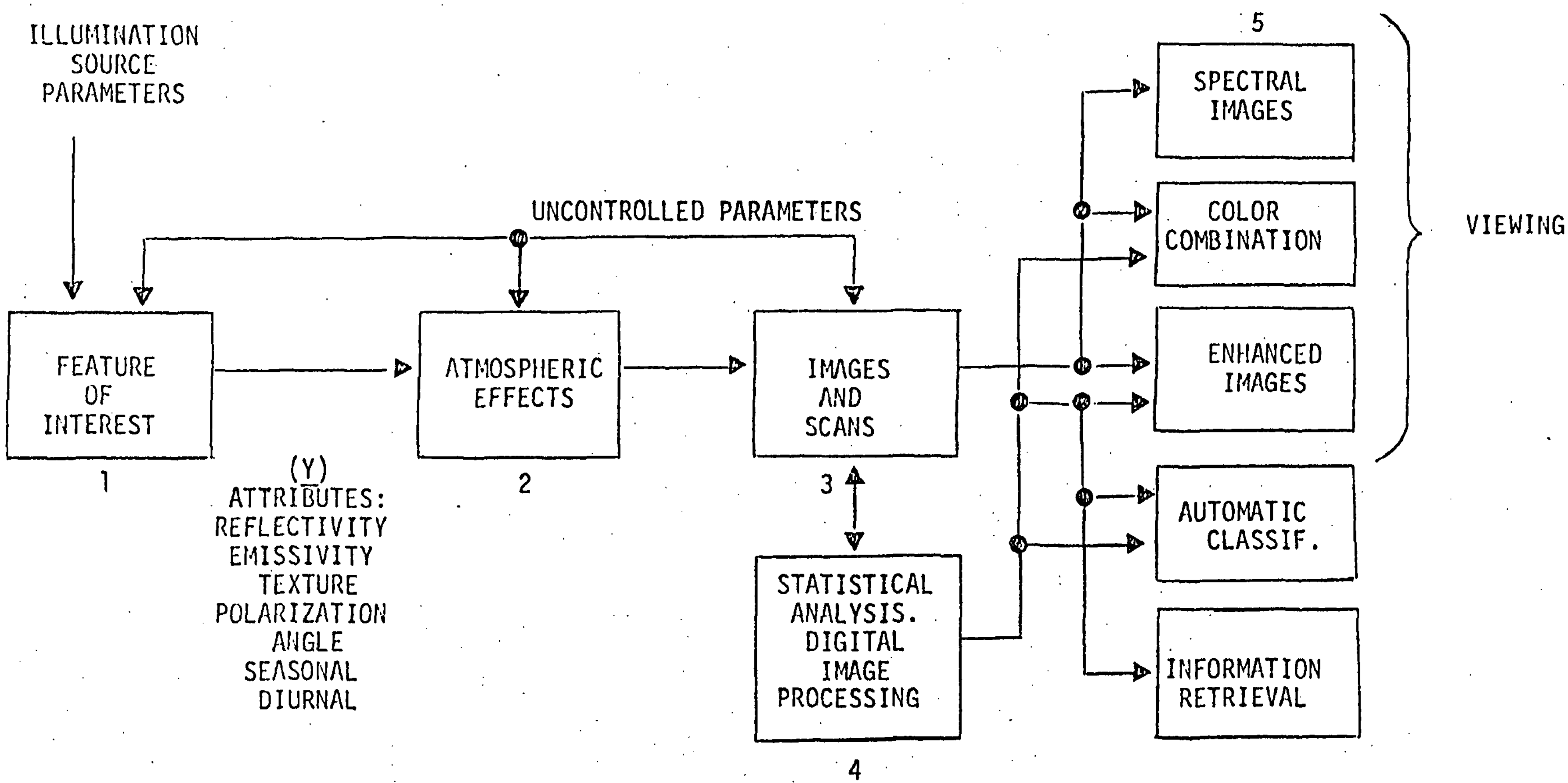


Figure 8.1. Flow diagram of the acquisition, analysis and enhancement of remote sensing images.

large, seven for ERTS 1, and the number of observed attributes can be even larger. Thus the intelligent exploitation of the relevant information requires the ability to handle large amounts of data in a concerted fashion. Our group, shown as block 4 in the diagram of Figure 8.1, brings to the integrated study both the experimental facility and personnel with the knowledge and background needed to perform the systematic exploitation of the available information. Such elaborate methods are most pertinent for tasks which cannot be done by directed observation of conventional black-and-white or color combined imagery. For this work the data processing facility being established as part of the University of California program emphasizes man-machine interaction rather than bulk processing of data. It uses as a central processing element a digital computer; thus the development of use of data processing algorithms becomes principally a problem in computer software development. With this approach it becomes possible to make use of the very extensive digital computation facility already available at the University of California. By the acquisition of a very modest number of specialized computer peripherals, an extremely versatile and flexible facility is being made available to the program. This digital signal processing facility, is described briefly later in this report.

Our facility and programs allow us to answer among other the following questions for the various investigations in our integrated study:

1. Which spectral bands and what resolution capabilities are needed in a specific discrimination problem?

2. How should spectral bands be combined to perform feature enhancement?

3. How well can *a priori* information (e.g., signature analysis) be relied upon to design enhancement algorithms?

To handle these questions our approach is to rely both upon ground truth and the images transmitted from ERTS 1. For digitized images a quantitative analysis is conducted of the effect on spectral components as well as on texture of images due to the features of interest. The results of this analysis in the form of one and multidimensional histograms, Fourier spectra, etc., allow us to eliminate irrelevant data, rank the usefullness of relevant data to a specific enhancement task, and guide the design of enhancement programs. Our philosophy is to perform the steps of the analysis rapidly using a small data array, observe intermediate results in color display, and make use of and try to quantify all clues available to a trained observer. This approach is being used with very promising results on ERTS 1 data, as we described later in this report.

8.2 WORK PERFORMED DURING THE PERIOD COVERED BY THIS REPORT

The progress to date on our part of the integrated study can be divided into the following broad categories:

1. Minor hardware modifications and improvements in the digital image processing facility central to our work.

2. Development of a very flexible programming system for interactive image handling and display.

3. Development of a systematic image enhancement procedure applicable to a variety of problems as well as to remote sensing.

4. Nonlinear equalization and calibration of the ERTS 1 MSS sensors.

5. Preliminary work on the combination of multispectral data for the study of Earth Resources.

6. Application of the procedure of 3) to ERTS 1 data and enhancement of imagery of interest to several participants of our integrated study.

7. Articulation and investigation of some of the basic issues which underly the interactive enhancement of remote sensing data by digital computers.

We shall avoid repetition of the major results reported in the Semi-Annual progress report and elaborate instead on the results obtained since January 1973.

8.2.1. DIGITAL PROCESSING FACILITY

The facility is shown in Figure 8.2 and is now operational. Modifications of the Image Processing Facility are still underway.

1. Replacement of a student build high resolution B/W display by a purchased unit of higher quality and better reliability. Some hardware modification is being carried out to increase the speed of display and to provide capability for color photography through color filters.

2. Acquisition and interfacing of a head-per-track digital disc storage. This unit will increase significantly the amount of rapid access digital storage available to us. This will result in a significant increase in the speed of several of the image processing algorithms we commonly use.

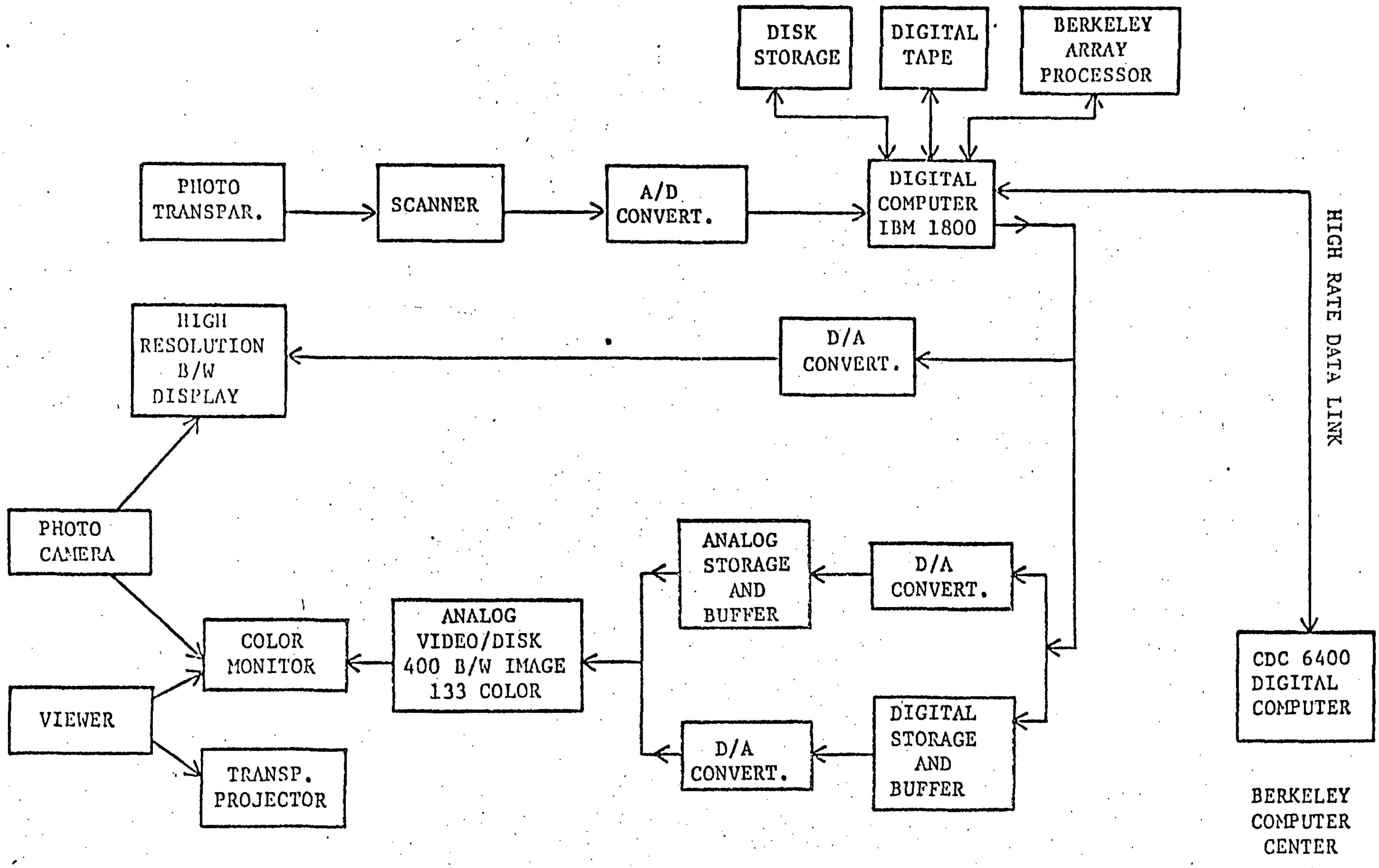


Figure 8.2. Digital Image Processing Facility

8.2.2 PICTURE PROCESSING PROGRAMMING SYSTEM (J. SCHRIEBMAN & B. ROMBERGER)

General Description

Due to the large number of specific operations of interest in our work it is necessary to provide a framework for the organization of user oriented image processing programs. To this end an image processing system has been developed.

The programming system can best be understood by considering a typical 'experiment'. The investigator has an ideal of what operations are necessary on the data to get the results he wants but is not usually sure of the exact parameters. He takes a sample data block and performs the series of steps necessary to get the results using his estimates of the parameters. Based on the results, the steps are performed again with altered parameters or possibly even an altered procedure to see the effect of the results. After a number of such tries, a procedure is developed which gives the best results. This procedure is then used on other data blocks.

Without some sort of programming system, each step in the above procedure requires one to start execution of the proper program and enter the data and parameters. It also requires one to keep track of intermediate results that are needed later and set up his own data storage. The system was developed to eliminate much of the work involved with these manual operations.

The basic objective of the system is interactive usage. During the trial phase, each step is performed as the user presents it to the system with intermediate results readily available so that he can tell how well

the procedure is working. He then runs through the entire procedure to look at the results. The procedure can be repeated with modifications or changes in the parameters to see the effect on the results. Once a procedure is finalized, it is possible to repeat it on a series of data.

A second object of the system is that it be easy to use. The user is able to sit at the console and type in the commands that tell the system what parameters to use. The syntax is fairly easy to understand without being overly restrictive or hard to expand.

A number of secondary user objectives are also met by the present system:

1. Parameters with a commonly used value have default values so that they do not have to be entered every time.

2. Parameters with restricted values are checked for validity.

3. Results (such as max or min) from one step are usable in further steps without requiring the user to remember and enter them.

4. The user is able to interrogate the system as to what programs are available, what data is presently accessible, what values parameters have and what parameters are required for each program.

5. Once the user determines a procedure, he is able to set up a whole series of commands for the system to execute without requiring his intervention at every step.

6. The system handles data storage space allocation unless the user wants to intervene.

A third objective of the system is that new processing programs can be added easily. This requires an easy procedure for telling the system what new programs has been added, what its parameters are and their restrictions,

how to set up data files or where to find input files, and what comments to give the user if he requests information on the program or its parameters.

A fourth objective is that the system be easy to implement. A balance must be reached between features wanted and difficulty of implementation. The system is designed in such a way to make check-out convenient, but is also flexible enough to make modifications and additions fairly easy.

System components, system user language, functions and commands, and an example of system use are described in the Semi-Annual progress report of December 31, 1972.

8.2.3 A SYSTEMATIC IMAGE ENHANCEMENT PROCEDURE

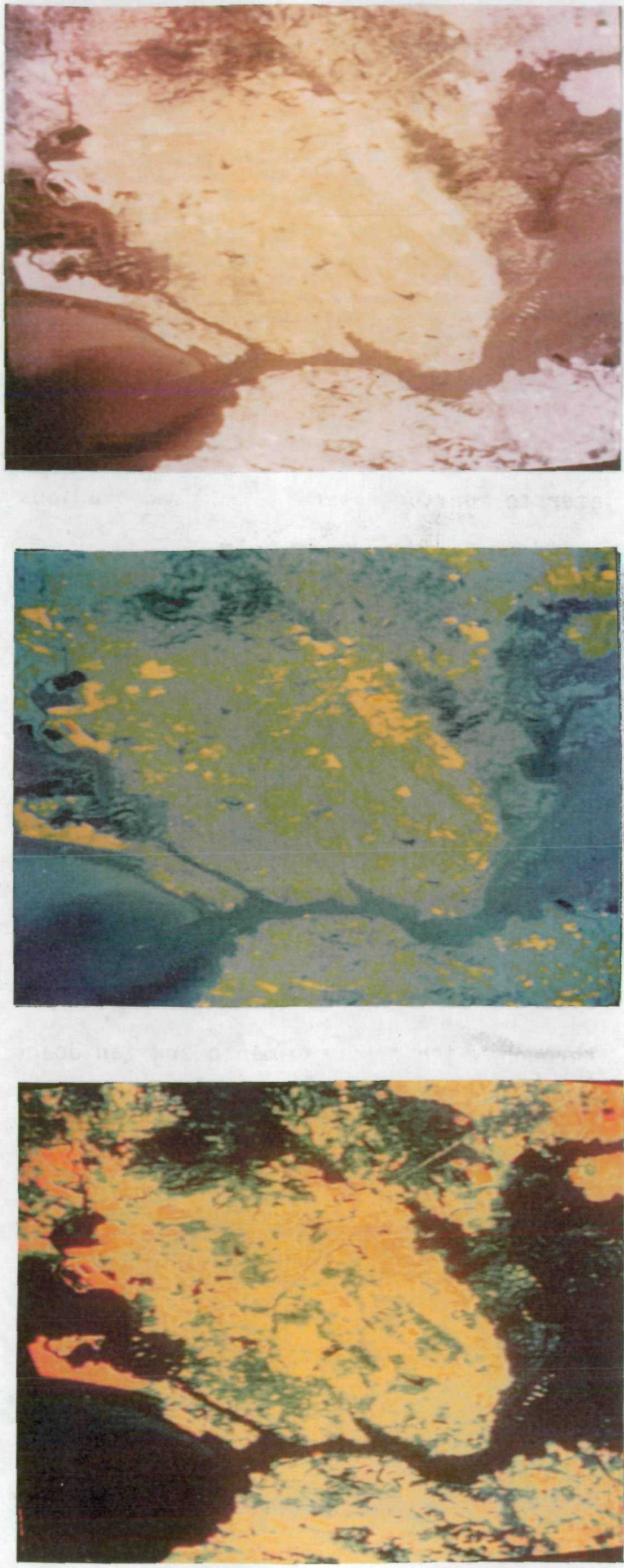
A systematic approach to the enhancement of images has been developed. This approach exploits two principal features involved in the observation of images: the properties of human vision and the statistics of the images being observed. A fairly detailed exposition of the technique has been presented in Appendix 1 of the December, 1972 progress report. The rationale of the enhancement procedure is reasonably simple: in the observation of some features of interest in an image, the range of objective luminance-chrominance values being displayed is generally limited and does not use the whole perceptual range of vision of the observer. The purpose of the enhancement technique presented is to expand and distort in a systematic way the grey scale values of each of the multispectral bands making up a color composite, to enhance the differential visibility of the features being observed. Thus, the enhancement is feature dependent and the work proceeds in the following steps.

1. Extraction of a geographic area of interest from NASA CCT and reformating for subsequent work.

2. Display on a color television monitor of standard color composites, to check for misregistration and to select subareas with features of interest.

3. Generate histograms in each of the spectral bands for subareas of the image which include features of interest. For instance we may wish to obtain maximum visibility in the water to monitor water quality and various types of water pollution.

In addition to the work reported earlier we wish to emphasize an aspect of our work of wide applicability which is the proper choice of pseudocolor scale for the display of a single spectral component or for the display of the output of a classification algorithm. In these applications it is important to preserve in the pseudocolor display the spatial resolution available in the original data. A pseudocolor scalar poorly chosen may lead to a significant degradation of the perceived details. This is illustrated quite well in Figure 8-3. Figure 8-3a is a enhanced black and white image of the Carquinez Straights, through which the Sacramento and San Joaquin Rivers outlet into the bay of San Francisco. In spite of the enhancement, an assessment of the grey scale is difficult to do and a pseudocolor display appears attractive. Figure 8-3b and 8-3c show two pseudocolor displays, 8-3b using a pure chrominance map, and the other a chrominance-luminance map discussed in a previous report. The advantage of the chrominance-luminance map is striking, in providing a considerably expanded perceptual scale without any loss of perceived spatial resolution. The same scale would be useful in displaying a color coded output of a classification algorithm in which the



a) Black and White Scale Enhanced

b) Pseudocolor Chrominance Scale

c) Pseudocolor Chrominance-Luminance Scale

FIGURE 8.3 - CARQUINEZ STRAIGHTS
(1002 - 18175) MSS BAND 5

the number of classes is large and the corresponding geographic areas quite detailed.

A slightly revised and expanded version of this work entitled "Digital Image Enhancement by Grey Scale Mapping" has been prepared for publication.

8.2.4 NONLINEAR EQUALIZATION AND CALIBRATION OF ERTS 1 MSS SENSORS

In some of the images distributed by NASA the stripping effect, due to different responses of the sensors in the Multispectral Scanner, is quite apparent. This effect is greatly magnified as one tries to enhance the images digitally for visibility in the water, since the range of useful sensor outputs is then quite narrow and data errors are more significant. It is possible to bring about some improvement on image quality by equalizing the sensors response on the basis of the statistics of the received data.

Some preliminary work, which equalizes offset and gain of the sensors, has not been too successful. The technique we currently use determines a nonlinear compensation curve for each of the sensors. This technique is described and illustrated in one of our ERTS 1 reports.

8.2.5 MULTISPECTRAL DATA COMBINATION

A problem of continuing interest in Remote Sensing in the rational use of multispectral data. The problem is inherently related to the limitation of a human observer to comprehend and correlate the information provided by too many sensors. This problem is already apparent with ERTS 1 data recorded

in 4 spectral bands. The conventional solution used by NASA is to provide color composites of either MSS bands 4,5, and 6 or MSS bands 4,5, and 7. We have undertaken a fairly long range, systematic study of this problem by considering in turn the following two important points:

1. The correlation and redundancy of the data itself from one spectral band to another.

2. The combined limitation of the reproduction media and of the human observer to discriminate information presented in image form.

The second point is related to our study of perceptual scales. More work is planned in this area, but we are currently limited in our ability to obtain quantitative, reproducible color reproductions. The precision CRT display currently being brought into operation will give us better control of photographic products.

At this time we shall report some preliminary results on the correlation and similarity in the ERTS 1 MSS data.

Correlation and Similarity of ERTS 1 Data

In the determination of the spectral bands of interest in specific applications of remote sensing one global measure of the additional information contributed by each spectral band is degree of correlation of this spectral band to all others. An alternative viewpoint is to consider how predictable is each spectral band given that all others are known. If, for instance, we were to find that MSS band 7 is completely predictable from the knowledge of MSS band 4,5 and 6, there would be no merit in processing and displaying MSS band 7 in addition to the other three bands.

These ideas can be formalized, using the framework statistics and estimation theory.

One traditional measure of similarity between two random variables x and y is the covariance, given by

$$\mu_{xy} = E[(x - m_x)(y - m_y)] \tag{1}$$

$$= E(xy) - m_x m_y$$

in which

$$m_x = E[x] = \int \alpha f_x(\alpha) d\alpha \tag{2}$$

$$E(xy) = \iint \alpha\beta f_{xy}(\alpha,\beta) d\alpha b\alpha \tag{3}$$

$f_x(\ )$ and $f_{xy}(\ ,\ )$ are the first and second order probability density functions of the random variables x and y.

Here x, y, etc., stands for the radiometric values in each of the spectral bands. We shall designate these random variables as I_4, I_5, I_6, I_7 to match the MSS band designation.

The probability density functions are obtained empirically from the data by forming one and two dimensional histograms.

Let

$$m_i = E[I_i] \tag{4}$$

$$\sigma_i^2 = E[I_i^2] - m_i^2 \tag{5}$$

$$\mu_{ij} = E[I_i I_j] - m_i m_j \tag{6}$$

$$\rho_{ij} = \frac{\mu_{ij}}{\sigma_i \sigma_j} \tag{7}$$

since $i,j = 1,2,3,4$ the $\{\mu_{ij}\}$ form a 4 x 4 symetric matrix, examples of which will be given later on.

The knowledge of the μ matrix allows the determination of the best linear estimate $\hat{I}_i$, of component I_i, given all other spectral components. The estimate takes the form

$$\hat{I}_i = \sum_{j \neq i} \alpha_j I_j + c_i \tag{8}$$

in which c_i is a constant.

If the estimate $\hat{I}_i$ is obtained only from one other spectral component I_j, then it can be shown that the resulting normalized mean-square error is given by

$$\varepsilon_{ij}^2 = \frac{E[(\hat{I}_i - I_i)^2]}{\sigma_i^2} = 1 - \rho_i^2 \tag{9}$$

clearly, this residual error measures the content of image I_i which is not predictable from I_j.

The ε_{ij}^2 form also a 4 x 4 matrix and $\varepsilon_{ii}^2 = 0$. Another approach to measuring the similarity between spectral components again considers mean-square estimation of one spectral component from another, but this time does not limit the form of the estimator to be linear. Given the observation of spectral component I_j we now write

$$\hat{I}_i = g(I_j) \tag{10}$$

in which $g(I_j)$ is chosen in such a way that

$$E[(I_i - g(I_j))^2] \tag{11}$$

is a minimum. It is known that we have then

$$\hat{I}_i = E[I_i | I_j] \tag{12}$$

$$\hat{I}_i(I_j) = \int \alpha f_{i/j}(\alpha/I_j)d\alpha \tag{13}$$

in which $f_{i/j}(\alpha/\beta)$ is the conditional probability density of I_i given that I_j has value $I_j = \beta$. These are classical results from estimation theory.

Because of the additional freedom allowed in the form of the estimator the nonlinear estimate will always outperform a linear estimate in the sense that the resulting normalized mean-square error $\eta_{ij}^2 < \varepsilon_{ij}^2$. In which

$$\eta_{ij}^2 = \frac{E[(I_i - g(I_j))^2]}{\sigma_i^2} \tag{14}$$

and ε_{ij}^2 is given by equation (9).

The interest of the result of equation (14) is that in the visual observation of spectral components, a human observer will conclude that no additional information is provided by spectral component I_i, if I_j is known, whenever $\eta_{ij}^2 = 0$, although ε_{ij}^2 may be different from zero. In other words, a human observer is not limited to perceiving linear relations between spectral components. To illustrate the idea, we show the results for two geographic regions in California.

Table 8.4 shows the covariance matrix $\{\mu_{ij}\}$, the linear error matrix $\{\varepsilon_{ij}\}$, and the nonlinear error matrix $\{\eta_{ij}\}$ for the data for Bucks Lake (1002-10125).

The μ matrix shows on its main diagonal, the variance of each spectral band. MSS band 4 has a small variance and generally gives a very flat image

when it is reproduced without enhancement. High entries off the main diagonal in the μ matrix indicate correlation between the corresponding spectral components. The error matrices are more informative from that standpoint. All entries are now normalized to 1 so that an entry $\varepsilon_{ij} = 0$ means I_i is perfectly predictable in terms of I_j, and $\varepsilon_{ij} = 1$ means that knowing I_j does not help at all in predicting I_j. Obviously we have $\varepsilon_{ii} = \eta_{ii} = 0$. We observe that MSS bands 6 and 7 are the most correlated and thus justify the common choice of discarding either MSS band 6 or MSS band 7 in color composition. Note however that MSS 4 and 5 are nearly as correlated and that almost as good a choice for the Bucks Lake as would be to discard either MSS band 4 or MSS band 5 and color combine the rest.

The comparison of the linear error matrix $\{\varepsilon_{ii}\}$ and the nonlinear error matrix $\{\eta_{ij}\}$ shows no significant differences.

Table 8.5 shows similar results for the farm land south of Isleton (1003-18175).

The interpretation of the results is generally as for Table 8.4 with some significant differences.

Note first that the data is considerably more active as indicated by the variances on the main diagonal of μ. Based on the linear error matrix one would conclude that MSS bands 4 and 5 are most correlated and thus a "best" color composite obtained from MSS band 4 or 5 and MSS bands 6 and 7. Given that the variance of MSS-5 is considerably larger than the variance of MSS band 4 for a composite without enhancement the obvious choice would be MSS bands 5, 6 and 7.

TABLE 8.4. BUCK'S LAKE
(1002 - 10125)

3.1	4.7	4.1	1.7
4.7	8.1	5.7	2.1
4.1	5.7	22.3	14.0
1.7	2.1	14.0	9.5

Covariance Matrix

$\mu = [\mu_{ij}]$

0	.35	.87	.95
.35	0	.90	.97
.87	.90	0	.28
.95	.97	.28	0

Linear Error Matrix

$\varepsilon = [\varepsilon_{ij}]$

0	.35	.81	.87
.36	0	.88	.93
.77	.79	0	.30
.85	.86	.30	0

Nonlinear Error Matrix

$\eta = [\eta_{ij}]$

TABLE 8.5. FARM LAND SOUTH OF ISLETON
(1003 - 18175)

7.18	13.0	4.5	.34
13.0	26.86	4.6	2.27
4.5	4.6	52.2	33.2
.34	2.27	33.2	27.1

Covariance Matrix

$\mu = [\mu_{ij}]$

0	.335	.97	.9997
.335	0	.992	.996
.97	.992	0	.468
.9997	.996	.468	0

Linear Error Matrix

$\varepsilon = [\varepsilon_{ij}]$

0	.32	.91	.88
.31	0	.92	.86
.96	.92	0	.29
.98	.90	.30	0

Nonlinear Error Matrix

$\eta = [\eta_{ij}]$

The nonlinear error matrix changes these conclusions because the entries are significantly different from the entries on the linear error matrix. In particular, bands 6 and 7 are now most correlated (correlated is a somewhat improper word and codependent would be more suitable).

The nonlinear dependence between spectral components is shown in Figure 8.6 in which are graphed the nonlinear estimates

$$\hat{I}_2 = g_{2,3}(I_3) \tag{15}$$

$$\hat{I}_2 = g_{2,4}(I_4) \tag{16}$$

$$\hat{I}_3 = g_{3,4}(I_4) \tag{17}$$

corresponding to equation 13.

These curves are quite nonlinear, even on the active range of the data. The random fluctuation at the top of the range are not significant and are due to the insufficient data which makes the estimator curve quite inaccurate.

Note that these results, based on correlation and similarity by pairs of spectral components are subject to revision whenever all spectral components are considered jointly. We have obtained some very encouraging preliminary results on the optimal linear combination in the form of equation 7 to reduce the 4 spectral components to 3 principal data set not identifiable directly with spectral components.

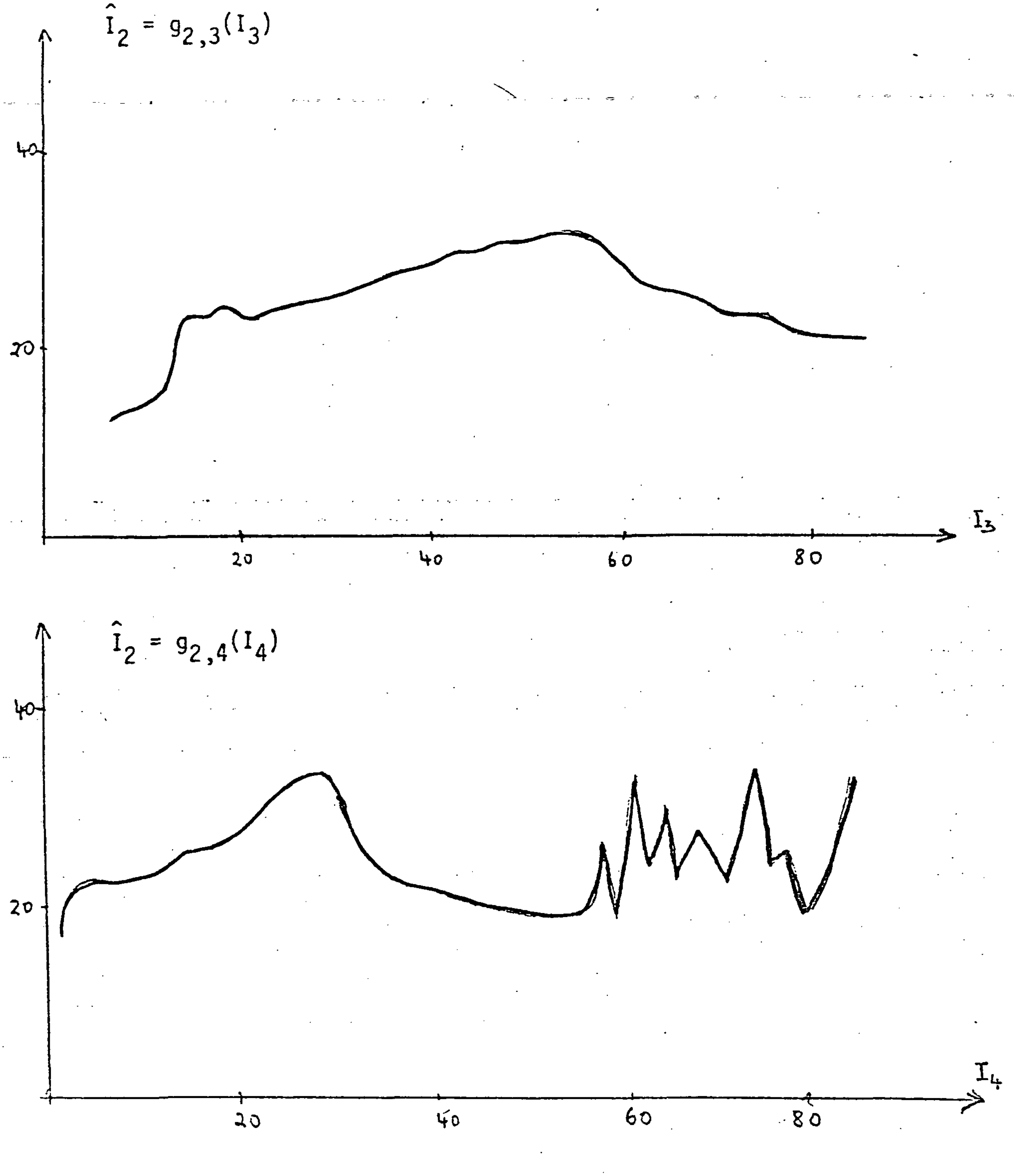


Figure 8.6. Nonlinear estimates of spectral components.

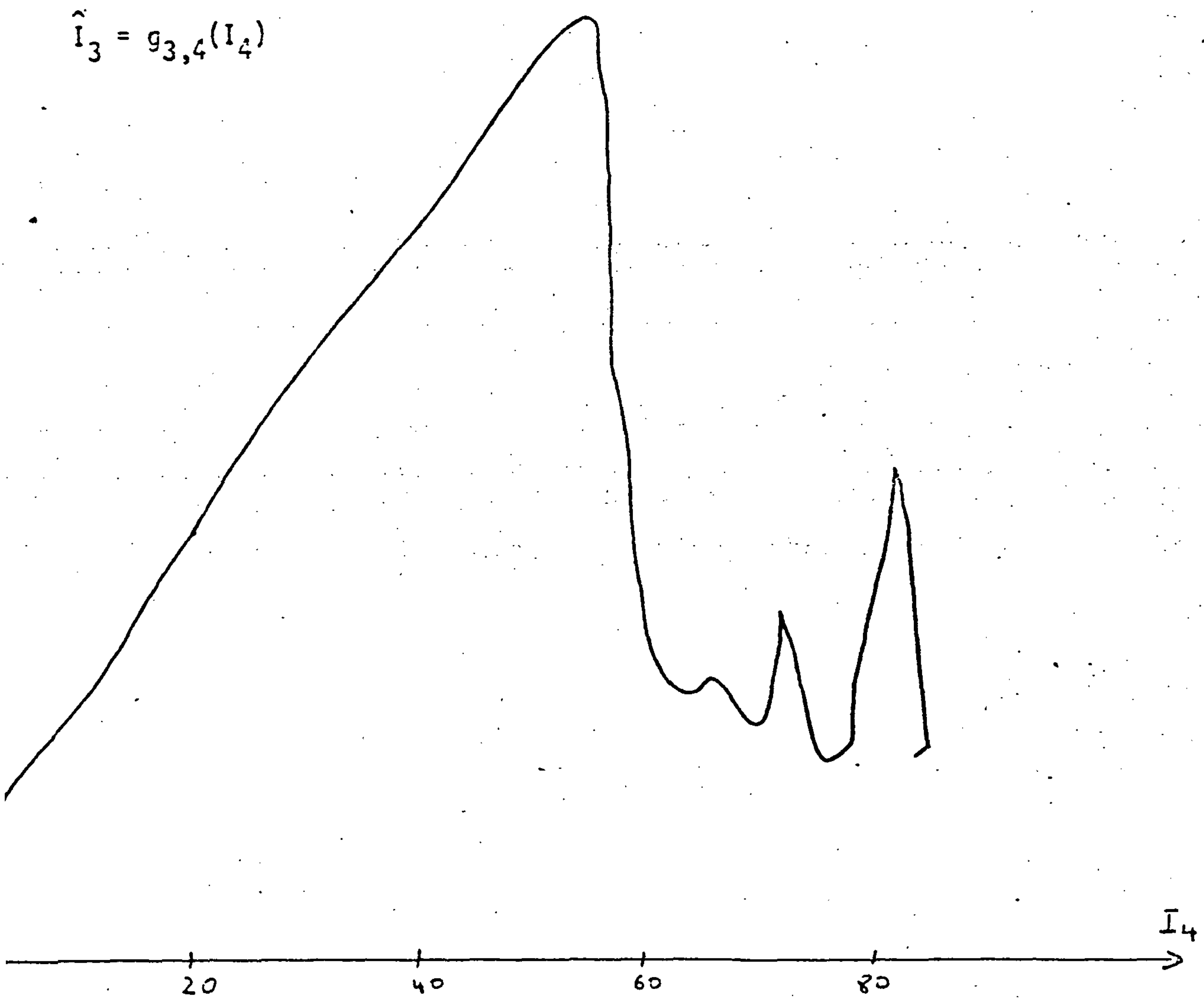


Figure 8.6 (continued)

NONLINEAR ESTIMATES OF SPECTRAL COMPONENTS

8.2.6 SUPPORT ACTIVITIES AND IMAGE ENHANCEMENT FOR OTHER PARTICIPANTS OF THE INTEGRATED STUDY.

A substantial part of our activities this year have been in support of the research and studies carried out by other participants of the Integrated Study of the State of California Using Remote Sensing Techniques.

Although a more substantial description of the studies is given in the appropriate chapters of this report we shall list briefly the investigators and the type of work considered.

1. Enhancement of ERTS 1 imagery to improve the visibility and mapping of frost damage eucalyptus trees in the Berkeley hills. This work is of prime interest to Dr. Robert N. Colwell, the principal investigator of the study.

2. Enhancement and Processing of ERTS 1 data to improve the visibility of sediments, pollutants and other indicators of water quality. This fairly extensive work, of interest to Dr. Robert Burgy, was carried out in consultation and cooperation with Jean Malingreau, also of the Department of Water Sciences and Engineering at the University of California, Davis.

3. Enhancement of ERTS 1 imagery to assist in the delineation and inventory of Earth Resources in wildlands and agricultural area of Northern California. This work was done to assist Dr. Don Lauer and Bill Draeger of the Forestry Remote Sensing Laboratory.

4. Scanning, digitization, processing and enhancement of imagery to assess the potential contributions of polarization information to the inventory and discrimination of Earth Resources. This substantial effort was carried out for Dr. Kinsell Coulson of the Davis Campus.

Enhanced ERTS Imagery was also supplied to Dr. John Tremor of NASA/ Ames Research Center, at his own request, to illustrate the information available in ERTS data and the capabilities of digital image enhancement to extract this information.

N74-14014

Chapter 9

INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER

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9.1 INTRODUCTION

Progress on this part of the project during the reporting period has been in the areas of (1) photographic recording and analysis of polarization effects, (2) the measurement and parameterization of the reflecting and polarizing properties of natural surfaces, (3) the measurement and parameterization of the intensity and polarization of the light incident at the surface from the sun and sky, and (4) computations of the intensity and polarization of light emerging from various models of the atmosphere.

The schematic diagram of Figure 9.1 gives an overview of the progress which has been made so far toward achieving the goal of predicting the quality (contrast, brightness, etc.) of images after they have been transferred from the surface to a sensor mounted on a remotely located platform. The very time consuming task of developing the dual channel polarizing radiometer is essentially complete; the only requirements remaining are minor modifications and adjustments of the instrument mount. The instrument itself provides polarization and intensity measurements of either the light from the sunlit sky or the light reflected from illuminated surfaces in eight different narrow wavelength bands from the ultraviolet, through the visible, and into the near infrared spectral

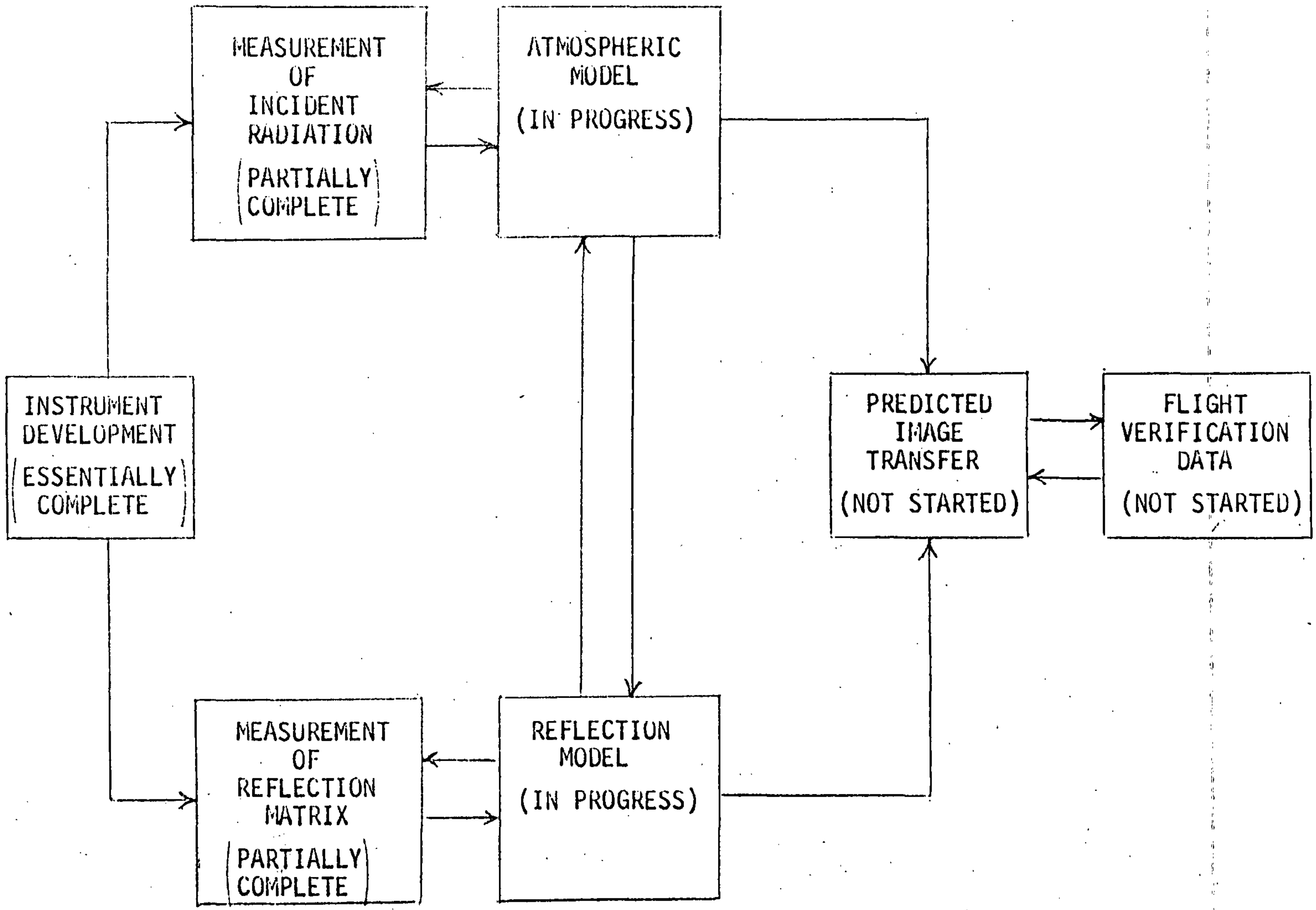

Figure 9.1. Summary of the progress which has been made so far toward the goal of predicting the quality of images after their being transferred through the atmosphere.

regions. These, of course, are the regions of principal interest in remote sensing applications. Operation of the instrument, including selection of color and neutral density filters, scanning of the observed direction in azimuth and elevation, and other mechanical movements are controlled completely by computer, thereby eliminating human errors which tend to degrade the quality of data in most measurement programs. In addition, the data are reduced to the physical quantities of intensity, degree of polarization, and orientation of the plane of polarization on a real time basis by the computer. This not only permits the rapid detection of any malfunction in the system, but it also largely eliminates the labor and expense of routine instrument operation and data reduction. A brief description of the instrument will appear in the June, 1973 issue of Applied Optics.

The instrument has been used for a number of basic measurements of the reflection properties of natural surfaces, mainly in the controlled conditions of the laboratory, and of the sunlight incident at surface level. The details of these sets of measurements and of their parameterization are outlined below. Remaining work in the area of surface measurements is the characterization of the light reflected from natural surfaces in realistic outdoor settings and further investigation of the light reaching the surface in various types of atmospheric conditions.

Mathematical modeling of the reflection properties of surfaces is under way, and reasonably good progress has been made on it. Modeling of the atmosphere is at the point where the computer programs are completed and appropriate values of the relevant parameters have been

determined. So far only preliminary calculations of the radiation fields have been performed. As indicated in the diagram of Figure 9.1, there are physical interactions between the atmospheric and surface models which must be considered. The prediction of actual image transfer, including the transfer of intensity, contrast, and polarization parameters through the atmosphere, is still a future activity, as is the verification of those predictions.

9.2 PHOTOGRAPHIC WORK

Photographic work during the period has proceeded along three lines. First, pairs of color photographs of landscapes were obtained with a polarizing filter superimposed in front of the camera lens and oriented with its plane of transmission parallel to the plane of polarization for one photo of the pair, and normal to the plane of polarization for the other photo of the pair. The photos were taken from the top of a 1500 foot television tower at the time of the passage of the ERTS-1 satellite on January 4, 1973. Typical results for the different orientations of the polarizing filter can be seen by the two pairs of photos of Figures 9.2 (a and b) and 9.3 (a and b). The increase of horizontal visibility obtainable by proper use of polarized light can be seen by comparing Figure 9.2b with Figure 9.2a, the effect showing up particularly well for the snow-capped Sierras at a distance of over 100 miles from the tower. The pair of photos constituting Figure 9.3 show the effects of polarization by reflection. The most obvious differences between the two photos are the lower general overall intensity for the case in which must of the reflected radiation is cut out

Figure 9.2a. Landscape photographed with plane of transmission of polarizing filter parallel to plane of polarization.

Figure 9.2b. Landscape photographed with plane of transmission of polarizing filter normal to plane of polarization.

Figure 9.3a. Landscape photographed with plane of transmission of polarizing filter parallel to plane of polarization.

Figure 9.3b. Landscape photographed with plane of transmission of polarizing filter normal to plane of polarization.

by the filter, and a difference in the appearance of rippled water. Not quite so obvious are the differences in the appearance of the fields in the two cases, but a careful examination will reveal details in one photo that cannot be seen in the other. For instance, the tracks of a vehicle, easily seen in the upper left corner of Figure 9.3a, can hardly be detected in Figure 9.3b, whereas the diagonal row pattern in the upper half of the photos is more obvious in Figure 9.3b than in Figure 9.3a. As in the previous case, the fraction of energy transmitted by the polarizing filter is dependent on filter orientation, making one of the two photos considerably brighter than the other.

A second type of photography was that of a motion picture obtained with a polarizing filter rotating in front of the camera lens. This technique, which was developed at UC Davis, shows polarization effects as a modulation of the intensity, the frequency of the modulation being twice that of the rotating filter. Thus it aids in visualizing polarizing effects in general, and reveals the objects in the photographed scene which polarize most strongly by reflection. About 150 feet of 16 mm color film were obtained with the technique from the television tower during the passage of the satellite mentioned above. The film shows some quite dramatic effects obtainable with polarized light.

The third, and certainly the most important, result of photographic work during the period was obtained as a joint effort with Dr. V. Algazi. It is a quantitative representation of polarization effects which occur in scenes such as landscapes, and there is every expectation that the technique will be applied relatively extensively in future studies

to aid in discriminating among various types of surfaces viewed from a remote location. The basic idea is the same as that described in the discussion of Figures 9.2 and 9.3 above. Two photographic negatives of the same scene are obtained, one photo in light of one plane of polarization and the other in light with the plane of polarization oriented normal to that of the first photo. The two negatives are then scanned by digital techniques, and the difference in the digital signals is computed. This difference, neglecting noise and other random effects, is due to the polarization of the light reaching the camera. Thus it is possible to build up a digitized polarization image of the scene, in place of the usual image resulting from light intensity only. The polarization image should reveal features not observable in the ordinary photographic image, and thus be a valuable tool for remote sensing applications. The polarization image may be improved by image enhancement techniques, once the digital scanning is performed, and thereby adapt the method for optimum use in revealing particular features of interest.

The results of a preliminary effort in this direction are shown in Figures 9.4a and 9.4b and in Figure 9.5. The first step in the process was to take two black-and-white photos in quick succession, with the polarizing filter in front of the camera lens oriented differently for the two. The photos were taken with a Speed Graphic camera from the top of the television tower near Walnut Grove on January 4, 1973. The negatives were then given to Dr. V. Algazi for digital processing through the following steps:

1. The two negatives were scanned, one at a time, by a 500-line digital scanner, and the results were put on magnetic tape. The amplitude of the signal from the scanner was inversely proportional to negative density. This resulted in two sets N_1 and N_2 of numbers, each set consisting of a value V_i for each of the resolution elements of the scanner. Each set could then be used to build up an image on a television monitor, which is the digitized analog of the original negative. Photos of images on the television screen corresponding to the two original negatives are shown for this case in Figures 9.4a and 9.4b.

2. The stored values of V_{i1} and V_{i2} from the two sets were used to compute a new value V_{i3} by the relation

$$V_{i3} = \left[\log V_{i1} - \log V_{i2}\right] + C$$

where C is a constant introduced to raise the level sufficiently to give always positive values of the logarithms. Thus a new image could be constructed from the composite of elements V_{i3}. Aside from the constant, non-zero values of V_{i3} resulted only in polarization effects in the original scene, so in a real sense the new image is a polarization photo.

3. Before this polarization image was constructed however, the set of V_{i3} was subjected to image enhancement to increase the spread of values and thus increase the contrast in the image.

4. The final step was to display the enhanced image on a color television screen and take a photo of the screen. The resulting photo for this case is shown in Figure 9.5. The scale was set so as to give a

Figure 9.4a. Photo of television screen displaying scene obtained by digital scanning.

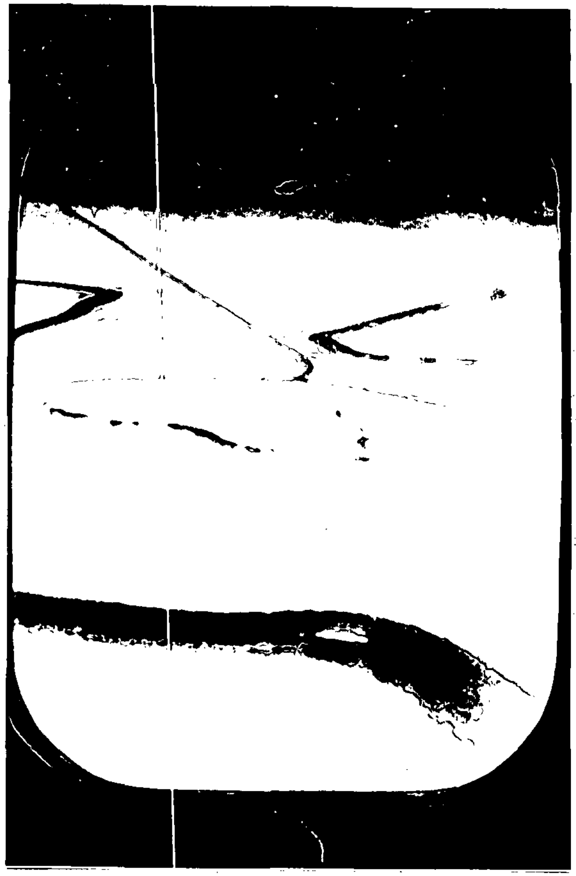

Figure 9.4b. Photo of television screen displaying scene obtained by digital scanning.

Figure 9.5 Polarization scene obtained from digital scans.

continuous progression of color from dark blue to red with an increase in the degree of polarization of the light from the original landscape.

A close examination of Figure 9.5 and a comparison with Figures 9.4a and 9.4b reveals many features which are readily apparent in the colored polarization image but which are either somewhat obscure or not seen at all in the original black-and-white photos. Water surfaces show up in the red end of the spectrum, as would be expected from the known polarizing properties of water. Considerable detail can be seen in the colored image of the canal, which appears to be absent from the originals. Details in the fields above and below the canal in the picture, the polarizing properties of which are not due to water, are much more apparent in the polarizing image than in those resulting from intensity alone, as are many small individual points along the roads and small streams in the upper half of the picture. It is possible, however, that some of the fine detail near the top edge may be due to slight inaccuracies in registration of the two negatives during the scanning process.

This preliminary example gives just an indication of the potential for the use of polarization in distinguishing features in natural situations. It must be realized that the processing methods have not been optimized in this initial effort, that the view angles were probably not ideal for showing polarization effects, and that the entire photographic spectrum was used for the original black-and-white photos. By more careful attention to the technical details and by a proper selection of film-filter combinations, it should be possible to take further advantage of polarization effects for image improvement and for use in the practical

problems of remote sensing. The possibilities will be investigated in more detail in the coming periods of this investigation.

9.3 MODELING OF THE REFLECTION MATRIX

The reflection of radiation from a surface can be completely described by a reflection matrix which specifies how the incoming Stokes vector which represents the incident radiation is transformed into the outgoing Stokes vector which represents the reflected radiation. Let the symbol Ω represent spherical coordinates θ and ϕ, and let $I_i(\Omega_0)$ represent the incoming Stokes vector which is incident at an angle Ω_0, and let $I_r(\Omega_1)$ represent the outgoing Stokes vector which is reflected at an angle Ω_1. The reflection matrix R is defined by the relationship

$$I_r(\Omega_1) = \int R(\Omega_1, \Omega_0) I_i(\Omega_0) d\Omega_0 \qquad [1]$$

This equation expresses in mathematical form a fundamental principle regarding reflected radiation:

IF THE RADIATION REFLECTED FROM A SURFACE IS TO BE DESCRIBED COMPLETELY, THEN IT IS NECESSARY TO KNOW THE COMPLETE ANGULAR DISTRIBUTION OF THE INCOMING RADIATION AND THE COMPLETE DEPENDENCE OF THE REFLECTION MATRIX ON THE INCOMING AND OUTGOING ANGLES.

In other words, if the radiation reflected from a surface is to be predicted, then the incident radiation must be measured and the reflection matrix must be determined in some manner beforehand. The determination of the incident radiation will be discussed in the next section. The rest of this section will be devoted to a discussion of the progress that has been made on the description of the reflection

matrix for natural surfaces.

Because equation [1] is an integral equation, it is not practical to determine the reflection matrix with a general source of incident radiation such as might be encountered outdoors. However, if indoor measurements are made with a collimated source of light that can be set to various incident angles and prepared with various states of polarization, then the reflection matrix can easily be determined since equation [1] reduces to

$$I_r(\Omega_1) = R(\Omega_1, \Omega_0)\, I_i(\Omega_0) \qquad [2]$$

In the last progress report laboratory measurements of the reflection matrix for several natural surfaces were presented. Although the reflection matrix could be represented by such a set of discrete data points, it would be more convenient to find a functional form which describes the data because a large number of discrete data points would be required to adequately represent the reflection matrix. To facilitate the parameterization of the reflection matrix a technique has been developed whereby the features of the surface of interest can be easily modeled.

It is necessary to make some fundamental assumptions before the reflection matrix of a surface can be modeled:

1. The characteristic properties of the surface may vary from point to point. It is assumed that for a sufficiently small area ΔA, of the surface these properties can be represented by some average values.

2. The area ΔA is assumed to be small compared to the total sample area A.

3. The components of the reflected electric vector are assumed to be linear with respect to the components of the incident vector.

Parameterization of the reflection matrix can be broken into three parts:

1. Effects due to multiple reflections of the radiation
2. Characteristics due to the roughness of the surface
3. Characteristics of the surface independent of surface structure.

These three effects are treated separately by attacking the problem in the following way. The single reflection of radiation from a small area ΔA with some local normal $\hat{n}$ is parameterized. The corresponding reflection matrix is called

$$M(\Omega_{1L},\Omega_{0L}) = M(\Omega_1,\Omega_0,\Omega_n) \qquad [3]$$

where Ω_{1L} and Ω_{0L} represent the outgoing and incoming spherical coordinates with respect to the local normal, and Ω_n represents the spherical coordinates of the normal direction. A distribution function of local normals for the entire surface, $P(\Omega_n)$, which describes the surface roughness is assumed. The mean reflection matrix for <u>single</u> scattering for the entire surface in terms of M and P is

$$R_1(\Omega_1,\Omega_0) = \int M(\Omega_1,\Omega_0,\Omega_n)P(\Omega_n)d\Omega_n \Big/ \int P(\Omega_n)d\Omega_n \qquad [4]$$

Given the complete angular dependence of R, the effects of multiple scattering can easily be calculated using equation [1]. For example, the contribution to the reflection matrix for double scattering is

$$R_2(\Omega_1,\Omega_0) = \int R_1(\Omega_1,\Omega_2)\cdot R_1(\Omega_2,\Omega_1)\,d\Omega_2 \qquad [5]$$

(Equation [5] assumes that the distribution of surface normals for the second reflection is the same as the distribution for the first scattering, although this restriction need not be enforced.)

The M-matrix of equation [3] can be written explicitly in terms of the reflection properties of an optically flat surface. If E_ℓ, E_r represent the components of the electric vector for incident radiation and E'_ℓ, E'_r represent the components of the electric vector for reflected radiation, then the properties of an optically flat surface are described by the relationships

$$E'_\ell(\Omega_{1L}) = A_{11}(\Omega_{1L},\Omega_{0L})E_\ell(\Omega_{0L}) + A_{12}(\Omega_{1L},\Omega_{01})E_r(\Omega_{0L})$$

and [6]

$$E'_r(\Omega_{1L}) = A_{21}(\Omega_{1L},\Omega_{0L})E_\ell(\Omega_{0L}) + A_{22}(\Omega_{1L},\Omega_{0L})E_r(\Omega_{0L})$$

The derivation of the M-matrix in terms of the physical quantities A_{11}, A_{12}, A_{21}, A_{22} is too long to include here, but the results of that derivation will be given to indicate the complexity of the relationship.

The M-matrix is

$$M_{11} = r_{11}$$

$$M_{12} = r_{12}C + r_{13}D$$

$$M_{13} = -r_{12}D + r_{13}C$$

$$M_{14} = 0$$

$$M_{21} = r_{21}C' + r_{31}D'$$

$$M_{22} = (r_{22}C + r_{23}D)C' + (r_{32}C + (r_{32}C + r_{33}D)D'$$

$$M_{23} = (-r_{22}D + r_{23}C)C' + (-r_{32}D + r_{33}C)D'$$

$$M_{24} = 0$$

$$M_{31} = -r_{21}D' + r_{31}C'$$

$$M_{32} = -(r_{22}C + r_{23}D)D' + (r_{32}C + r_{33}D)C'$$

$$M_{33} = -(-r_{22}D + r_{23}C)D' + (-r_{32}D + r_{33}C)C'$$

$$M_{34} = 0$$

$$M_{41} = M_{42} = M_{43} = 0$$

$$M_{44} = r_{44}$$

where

$$r_{11} = (A_{11}^2 + A_{12}^2 + A_{21}^2 \; A_{22}^2)/2$$

$$r_{12} = (A_{11}^2 - A_{12}^2 + A_{21}^2 - A_{22}^2)/2$$

$$r_{13} = A_{11}A_{12} + A_{21}A_{22}$$

$$r_{21} = (A_{11}^2 + A_{12}^2 - A_{21}^2 - A_{22}^2)/2$$

$$r_{22} = (A_{11}^2 - A_{12}^2 - A_{21}^2 + A_{22}^2)/2$$

$$r_{23} = A_{11}A_{12} - A_{21}A_{22}$$

$$r_{31} = A_{11}A_{21} + A_{12}A_{22}$$

$$r_{32} = A_{11}A_{21} - A_{12}A_{22}$$

$$r_{33} = A_{11}A_{22} + A_{21}A_{12}$$

$$r_{44} = A_{11}A_{22} - A_{21}A_{12}$$

and

$$C = A_0^2 - B_0^2 \qquad D = 2A_0B_0$$

$$C' = A_1^2 - B_1^2 \qquad D' = 2A_1B_1$$

where

$$A_0 = [\mathrm{Sin}\ \theta_0\ \mathrm{Cos}\ \theta_n - \mathrm{Cos}\ \theta_0\ \mathrm{Sin}\ \theta_n\ \mathrm{Cos}(\phi_0 - \phi_n)]/\mathrm{Sin}\ \phi_{0L}$$

$$B_0 = \mathrm{Sin}\ \theta_n\ \mathrm{Sin}\ \phi_{0L}/\mathrm{Sin}\ \theta_0$$

$$A_1 = [\mathrm{Sin}\ \theta_1\ \mathrm{Cos}\ \theta_n - \mathrm{Cos}\ \theta_1\ \mathrm{Sin}\ \theta_n\ \mathrm{Cos}(\phi_1 - \phi_n)]/\mathrm{Sin}\ \theta_{1L}$$

$$B_1 = \mathrm{Sin}\ \theta_n\ \mathrm{Sin}\ \phi_{1L}/\mathrm{Sin}\ \theta_1$$

Expressions for θ_{0L}, ϕ_{0L}, θ_{1L}, ϕ_{1L} can be derived from the relationships

$$\mathrm{Sin}\ \theta_{0L}\ \mathrm{Cos}\ \phi_{0L} = \mathrm{Sin}\ \theta_0\ \mathrm{Cos}\ \theta_n\ \mathrm{Cos}(\phi_0 - \phi_n) - \mathrm{Cos}\ \theta_0\ \mathrm{Sin}\ \theta_n$$

$$\mathrm{Sin}\ \theta_{0L}\ \mathrm{Sin}\ \phi_{0L} = \mathrm{Sin}\ \theta_0\ \mathrm{Sin}(\phi_0 - \phi_n)$$

$$\mathrm{Cos}\ \theta_{0L} = \mathrm{Cos}\ \theta_0\ \mathrm{Cos}\ \theta_n + \mathrm{Sin}\ \theta_0\ \mathrm{Sin}\ \theta_n\ \mathrm{Cos}(\phi_0 - \phi_n) \qquad [7]$$

$$\mathrm{Sin}\ \theta_{1L}\ \mathrm{Cos}\ \phi_{1L} = \mathrm{Sin}\ \theta_1\ \mathrm{Cos}\ \theta_n\ \mathrm{Cos}(\phi_1 - \phi_n) - \mathrm{Cos}\ \theta_1\ \mathrm{Sin}\ \theta_n$$

$$\mathrm{Sin}\ \theta_{1L}\ \mathrm{Sin}\ \phi_{1L} = \mathrm{Sin}\ \theta_1\ \mathrm{Sin}(\phi_1 - \phi_n)$$

$$\mathrm{Cos}\ \theta_{1L} = \mathrm{Cos}\ \theta_1\ \mathrm{Cos}\ \theta_n + \mathrm{Sin}\ \theta_1\ \mathrm{Sin}\ \theta_n\ \mathrm{Cos}(\phi_1 - \phi_n)$$

Modeling of the reflection matrix consists of (1) parameterizing the functions A_{11}, A_{12}, A_{21}, and A_{22} of equations [6] in terms of physical quantities such as the index of refraction, and (2) parameterizing the normal distribution function $P(\Omega_n)$ to describe the surface structure. Computer programs are being developed that will allow the complete reflection matrix to be calculated by the method which has just been discussed. Several simple models for A_{11}, A_{12}, A_{21}, A_{22}, and $P(\Omega_n)$

will be tried in hopes of finding a simple parameterization of the reflection matrix for several natural surfaces that will involve just a few fundamental parameters.

9.4 MEASUREMENTS OF RADIATION INCIDENT AT THE SURFACE

As is well known, the characteristics of a landscape may be observed to greater advantage under one lighting condition than under another. The properties of the reflected light are a function of the direction, intensity, spectral distribution, and polarization of the incident light, as well as of the details of the surface itself. Thus by knowing the transfer matrix of the atmosphere and the reflection matrix of the surface material, it is possible in principle to compute the entire Stokes vector for the light reflected from the surface and used to characterize the surface from a remotely located platform. The atmospheric transfer matrix must be known for a variety of atmospheric conditions in order to provide flexibility in the remote sensing application, the conditions to include both very clear atmospheric cases, very turbid cases, and various conditions between.

We were fortunate to get an opportunity during the reporting period to measure the Stokes parameters of light reaching the surface under extremely clear atmospheric conditions. This was made possible by cooperating (at relatively little cost to this project) with another investigation designed to detect atmospheric aerosols by their effect on skylight polarization at the Mauna Loa Observatory on the island of Hawaii. The joint measurement program was carried out there during February and March, 1973. Although data reduction and analysis are not

complete, some preliminary results are available.

The Mauna Loa Observatory, at an altitude of about 11,200 feet, is characterized by extremely clear atmospheric conditions. Not only does it have generally oceanic conditions, but also the Observatory is protected from local sources of contamination by being above the trade wind temperature inversion. It is the site of the climatological monitoring station of the National Oceanic and Atmospheric Administration, and therefore has the facilities necessary for instrument operations.

The observational program consisted of repeated measurements of the intensity and state of polarization of the light from the sunlit sky, the measurements being made in eight different wavelengths and at intervals of sometimes two and sometimes five degrees of angle throughout the plane of the sun's vertical. In the interests of simplicity, data were taken only in cases in which the sky was less than one tenth covered with clouds.

Figure 9.6 shows a typical set of measurements of the polarization taken at the Mauna Loa Observatory on March 25. During the period of measurement there were 21 days suitable for collection of data. A total of 372 runs similar to Figure 9.6 were made at wavelengths from 3200 to 9000 Angstroms. Approximately 185,000 data values were recorded on magnetic tape during this period.

In order to study the behavior of the polarization in detail, a functional form was used to parameterize the data. Let θ be the scattering angle defined as the angle between the sun and direction of observation in the plane defined by the sun, the observer, and the

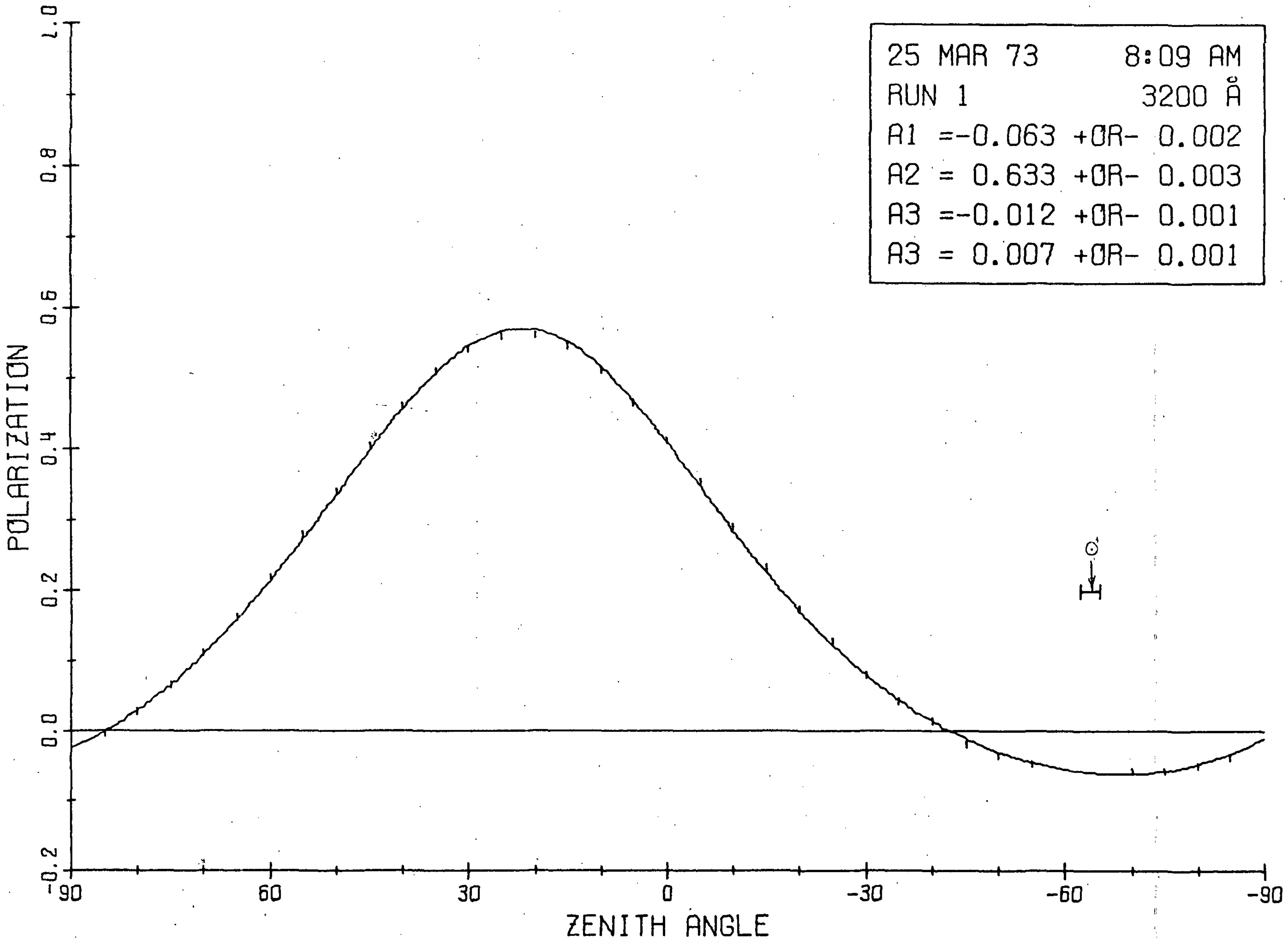

Figure 9.6. Polarization in the plane of the sun at Mauna Loa Observatory on March 25, 1973 at 8:09 AM and 3200 Angstroms.

zenith. It was found that the phenomenological form

$$P(\theta) = A_0 + A_1R(\theta) + A_2\text{Sin } 2\theta + A_3\text{Sin } 4\theta,$$

where $R(\theta) = (1 - \text{Cos}^2\theta)/(1 + \text{Cos}^2\theta)$ is the Rayleigh phase function, described the angular dependence adequately. The values of the parameters A_0, A_1, A_2, and A_3 and the resulting fit are shown in Figure 9.6 for those particular data.

The behavior of the parameters A_0, A_1, A_2, and A_3 on a typical day are shown in Figures 9.7, 9.8 and 9.9. Figure 9.7 shows the parameter for the Rayleigh phase function, A_1, during the morning. A_1 is largest at approximately 6000 Angstroms, and decreases from early morning to forenoon. Figure 9.8 shows the parameters A_0, A_2, and A_3 for the same time period. Each of these parameters has a definite characteristic dependence on wavelength. A_2 and A_3 show little change (except for approximately 1 percent scatter), while A_0 decreases at the shorter wavelengths as the day progresses. Figure 9.9 shows the parameter A_1 from late afternoon to sunset.

Not all of the data from the Mauna Loa Observatory have been analyzed as yet, so it is too early to say anything more about these measurements. However, it is promising that the polarization data can be parameterized with a simple form. When a complete parameterization of the incident radiation has been achieved, then the reflection data for natural surfaces can be used to predict the Stokes vector for for the reflected radiation, and this prediction can be checked against outdoor measurements of the actual reflected radiation as measured by

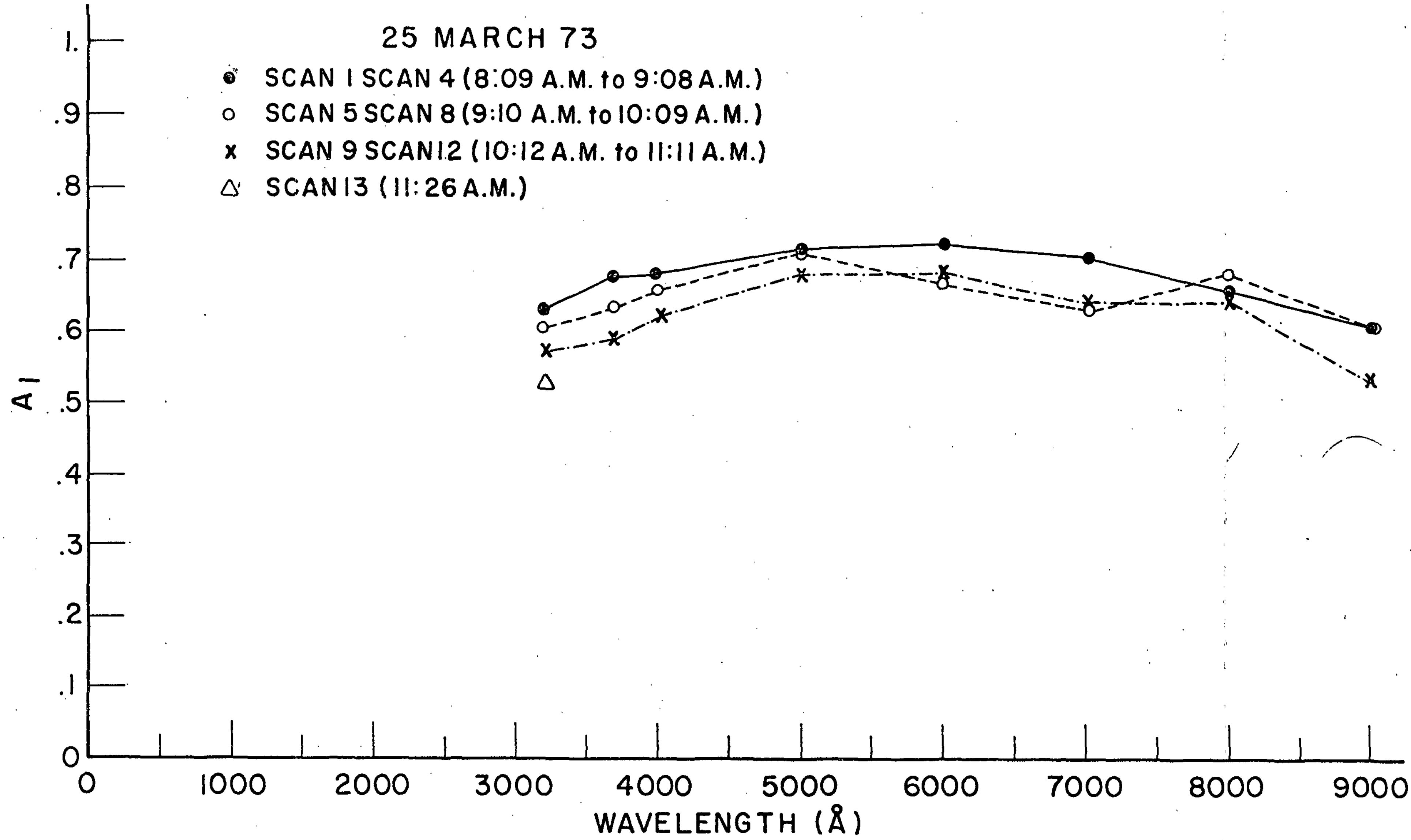

Figure 9.7. Values of the parameter A_1 for the morning of March 25.

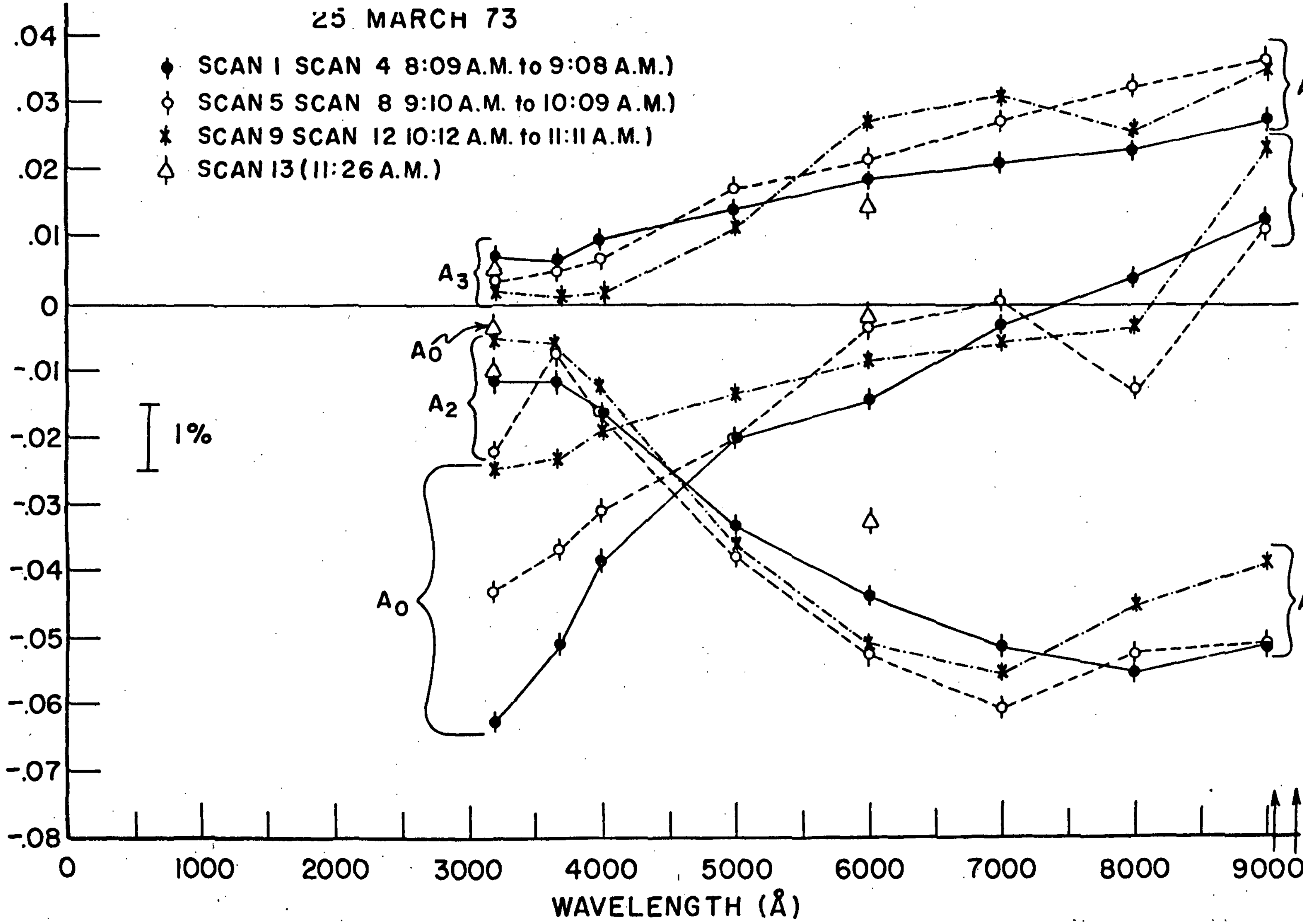

Figure 9.8. Values of the parameters A_0, A_2, and A_3 for the morning of March 25.

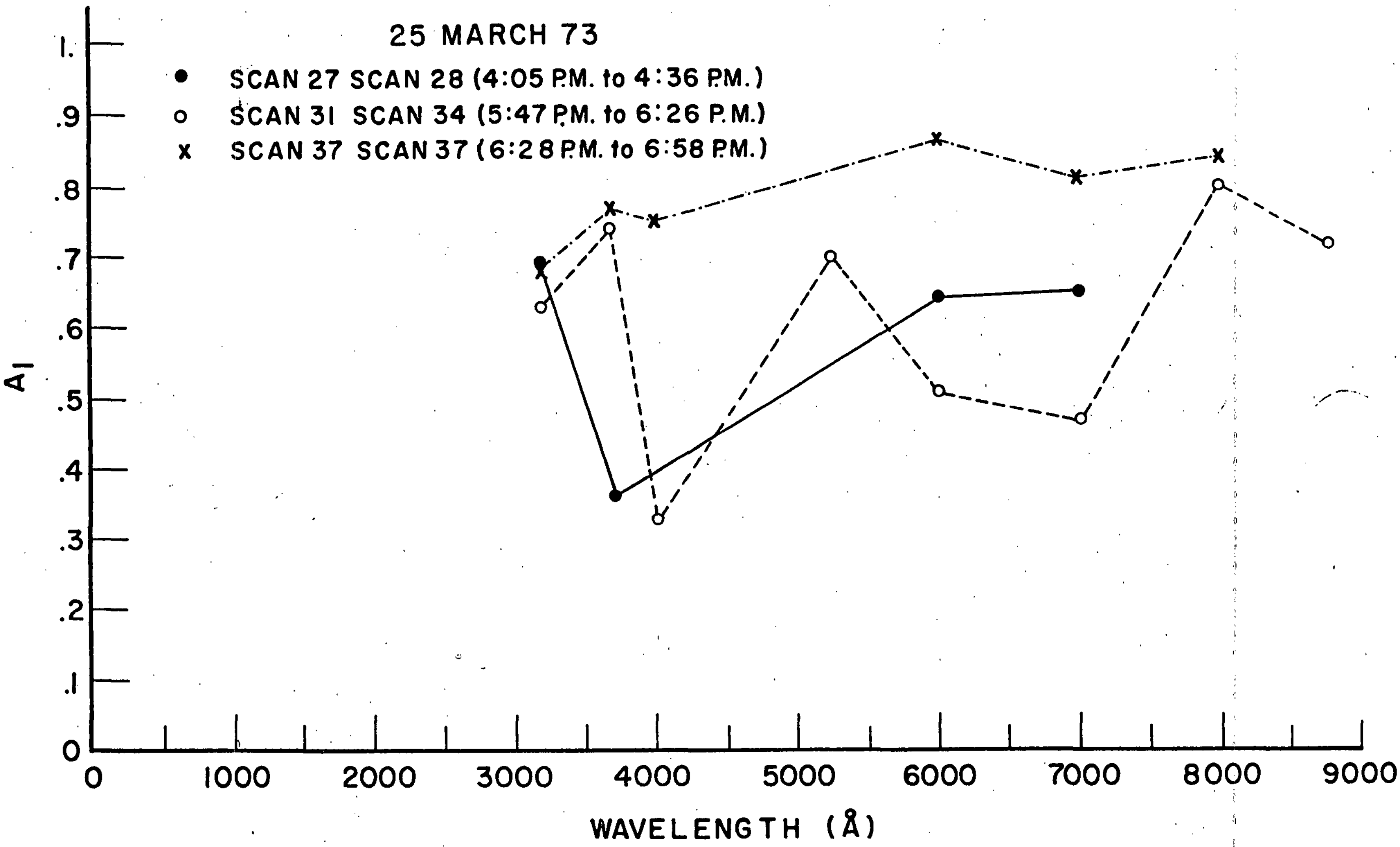

Figure 9.9. Values of the parameter A_1 for the late afternoon of March 25.

the polarizing radiometer.

9.5 ATMOSPHERIC MODEL COMPUTATIONS

Effort in this area has been confined during the period to the development of computer programs for computing the characteristics of radiation emerging upward and downward from the atmosphere. All of the four Stokes parameters are included, so as to retrieve the entire information contained in the radiation stream.

The models considered so far are the clear Rayleigh atmosphere and an atmosphere with a number N aerosol particles per unit volume of a size distribution which follows the power law

$$dN/dr = ar^{-b}$$

where r is particle radius and a and b are constants. There is some evidence that this distribution is an approximate description of the mean worldwide aerosol characteristics, but in reality it does not necessarily describe the aerosols in a given atmospheric situation. Since aerosol properties vary widely in short periods of time at a given location, and even more widely among various locations, any model must be viewed as only an example of possible aerosol characteristics, and not necessarily those which exist at a given time. Thus it will be necessary to study a considerable number of different models in order to establish the types of variations to be expected.

As mentioned in a previous report, a set of computer programs for aerosol computations has recently been developed under NASA sponsorship

by Dr. J. V. Dave of IBM in Palo Alto. A copy of these programs has now been obtained for use in the present study. It is planned to adapt the programs appropriately for specific atmospheric models in order to decrease the computer time requirements, which tend to be excessive in their present format. These modifications and use of the programs in computations of image transfers will be carried out in the coming period of the project.